FOGG, GREEN, NORRIS, RANDALL.

Lateral Pressure of Wet Concrete on Columm Forms

Civil Engineering

B. S.

1915

LATERAL PRESSURE
OF
WET CONCRETE ON COLUMN FORMS

BY

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THESIS

FOR THE

DEGREE OF BACHELOR OF SCIENCE

IN

CIVIL ENGINEERING

COLLEGE OF ENGINEERING

UNIVERSITY OF ILLINOIS

1915

UNIVERSITY OF ILLINOIS

June 1, 1915. 191

THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

A. K. Fogg, Ralph Green, W. K. Norris, and T. D. Randall

ENTITLED LATERAL PRESSURE OF WET CONCRETE ON COLUMN FORMS

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Civil Engineering

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I. INTRODUCTION.

1. STATEMENT OF PROBLEM. The proper design and construction of the forms for concrete structures are essential factors of the work. Many failures due to the lack of knowledge of the action of wet concrete on forms have taken place since the introduction of concrete as a building material. Such failures usually occur in columns and posts, and are due to the high pressures caused by large masses of concrete. The breaking open of the forms entails temporary injury to the structure and incurs considerable delay and expense.

It is desirable to have accurate information concerning the pressure exerted by wet concrete so that the forms may be economically designed. On account of the high cost of lumber, the use of unnecessarily heavy forms incurs excessive expense. There are almost no data on the lateral pressure of green concrete. Hence, in order that the forms may be safely and economically designed and constructed, it is desirable to determine the lateral pressure exerted by wet concrete on forms.

2. PREVIOUS INVESTIGATIONS. Several investigations have been carried on in the past to determine the lateral pressure exerted by wet concrete on forms, but very little accurate information has been derived from them.

In 1894 Mr. Ernest McCullough made a series of tests * in which the pressures were measured by putting a 7/8-inch board in the side of a form and pouring in concrete until the board broke. The pressure obtained was equivalent to that of a liquid

* See Engineering News, July 18, 1910.

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

weighing about 80 lbs. per cu. ft. The weight of the equivalent liquid was probably only about half of that of the concrete. Owing to the crude manner in which these experiments were conducted, little importance can be attached to the results.

In 1908 a very extensive set of tests*, lasting throughout the whole season, was carried out by Major Francis R. Shunk during the construction of the Mississippi River Lock No. 1 near Minneapolis, Minnesota. The tests were made during the pouring of monolithic blocks of concrete 25.75 feet high. The concrete was very wet, and weighed about 152 lbs. per cu. ft. The lateral pressure was measured by means of a piston connected to a scale beam. The results indicated that a hydostatic pressure corresponding to that of a liquid weighing 152 lbs. per cu. ft. was obtained at first; but as the head increased the concrete began to act more as a solid, so that later the pressure remained practically constant. It was also found that the head at which the concrete began to act as a solid varied with the rate of pouring, the temperature, the pressure, and the condition of agitation of the surface. Notice that the weight of the equivalent liquid is the same as that of the concrete.

In 1913 Mr. E. B. Germain, assistant engineer for the Aberthaw Construction Company, carried on a series of tests+ during the construction of a mill building in Cambridge, Massachusetts. He used two columns 20 inches square and 20 feet high. A fairly wet 1:1 1/2:3 mixture was used. The gages were hot-water bottles filled with mercury, so that the lateral pressure could be measured by reading the level of the mercury in the tubes. The columns were poured very rapidly. A hydrostatic pressure equivalent to

* See Engineering News, September 9, 1909.
\+ See Engineering News, August 14, 1913.

that of a liquid weighing from 140 to 150 lbs. per cu. ft. was found.

3. SCOPE OF THIS INVESTIGATION. The purpose of this thesis is to determine the lateral pressure exerted by wet concrete upon forms of varying sizes under different conditions of pouring. Lateral pressures were measured at five points along the side of the column by diaphragm pressure gages. Two methods of pouring the concrete were used, the continuous and intermittent method. In the former case, the form was filled from an overhead skip at a uniform rate of flow. In the other case, the form was filled to a foot in depth, followed by an intermission of from 15 to 20 seconds, then a deposition of another foot of concrete, and so on. It was hoped that a study of the relative results obtained from these two methods of pouring would afford some information concerning the magnitude of the pressures due to impact.

II. DESCRIPTION OF APPARATUS.

4. COLUMN FORMS. The tests were made on 12-inch and 20-inch square column forms, the height being 12 feet in both cases. The forms were made of plank with ship-lap joints, and were built of sections which were interchangeable, 4-inch sections being added to the 12-inch form to make the 20-inch form. Fig. 1, page 4, shows the 12-inch size assembled; and also shows the interchangeable sections for the larger size. The parts of the forms were held together by wooden yokes and steel rods. No trouble was experienced with leakage from the forms. Five threaded cast-iron rings to hold the pressure gages were set into the column forms as shown in Fig. 1, page 4.

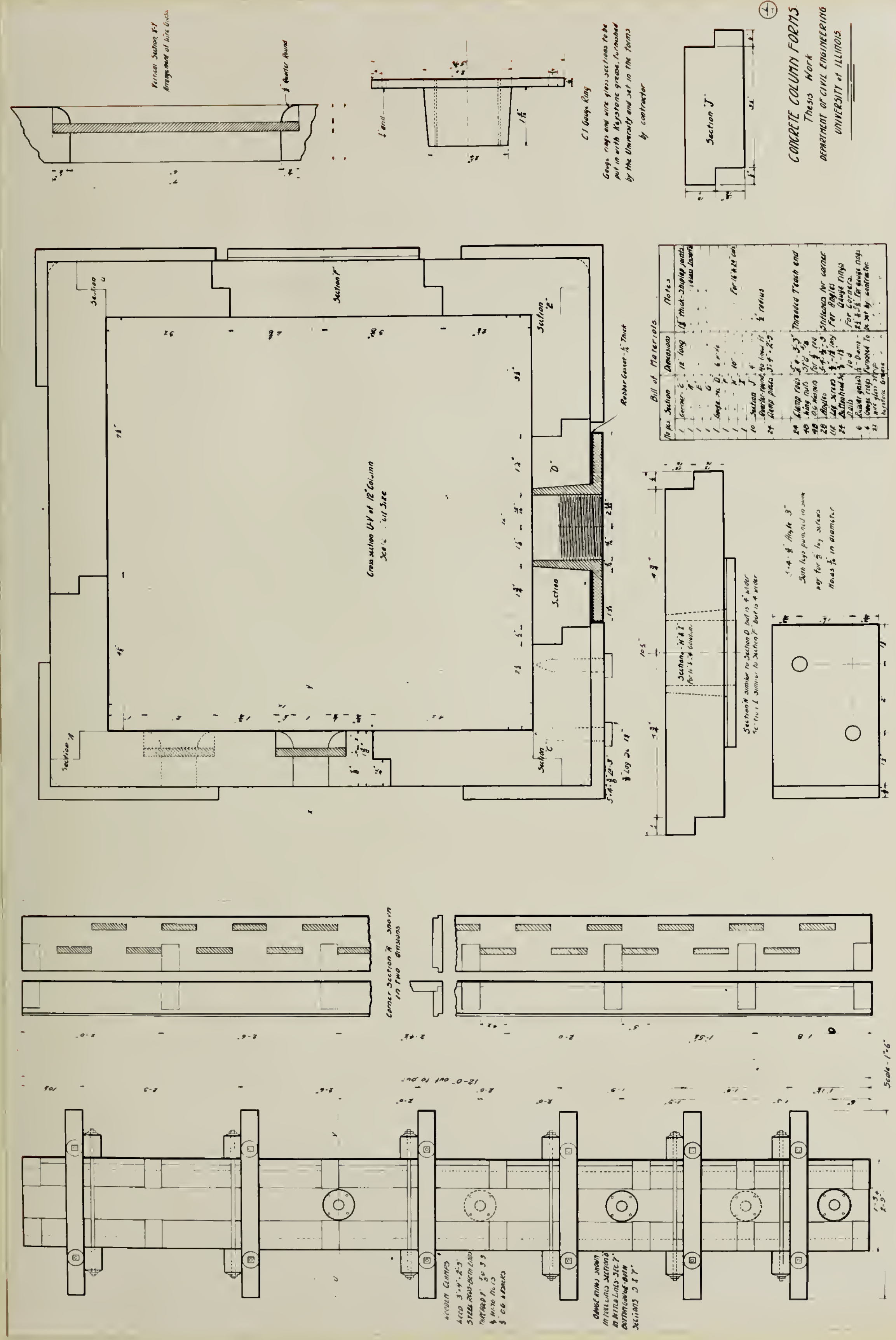

CONCRETE COLUMN FORMS
Thesis Work
DEPARTMENT OF CIVIL ENGINEERING
UNIVERSITY of ILLINOIS
Bill of Materials
Cross section U-V of 12" Column
Section 'J'
Scale - 1"-6"

Fig. 1

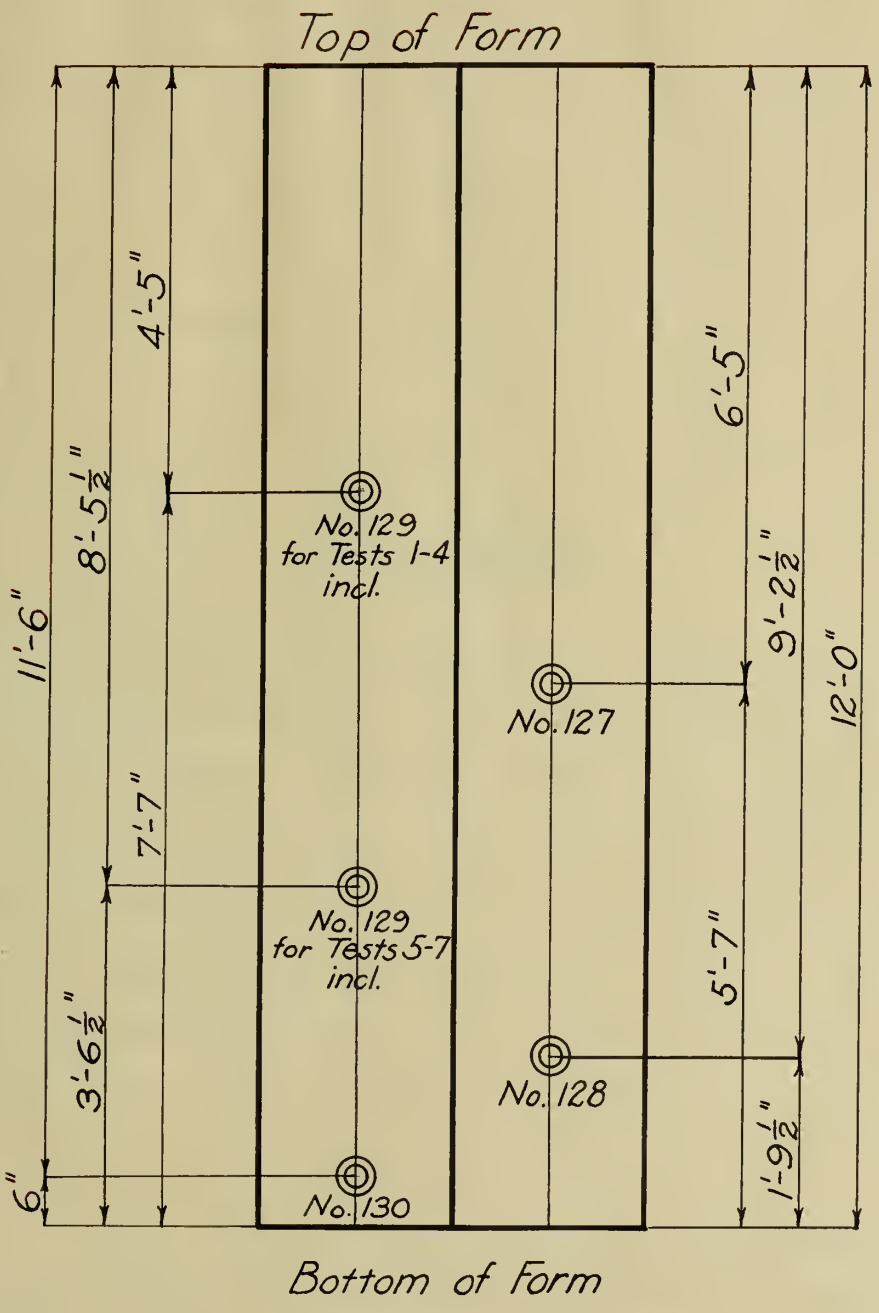


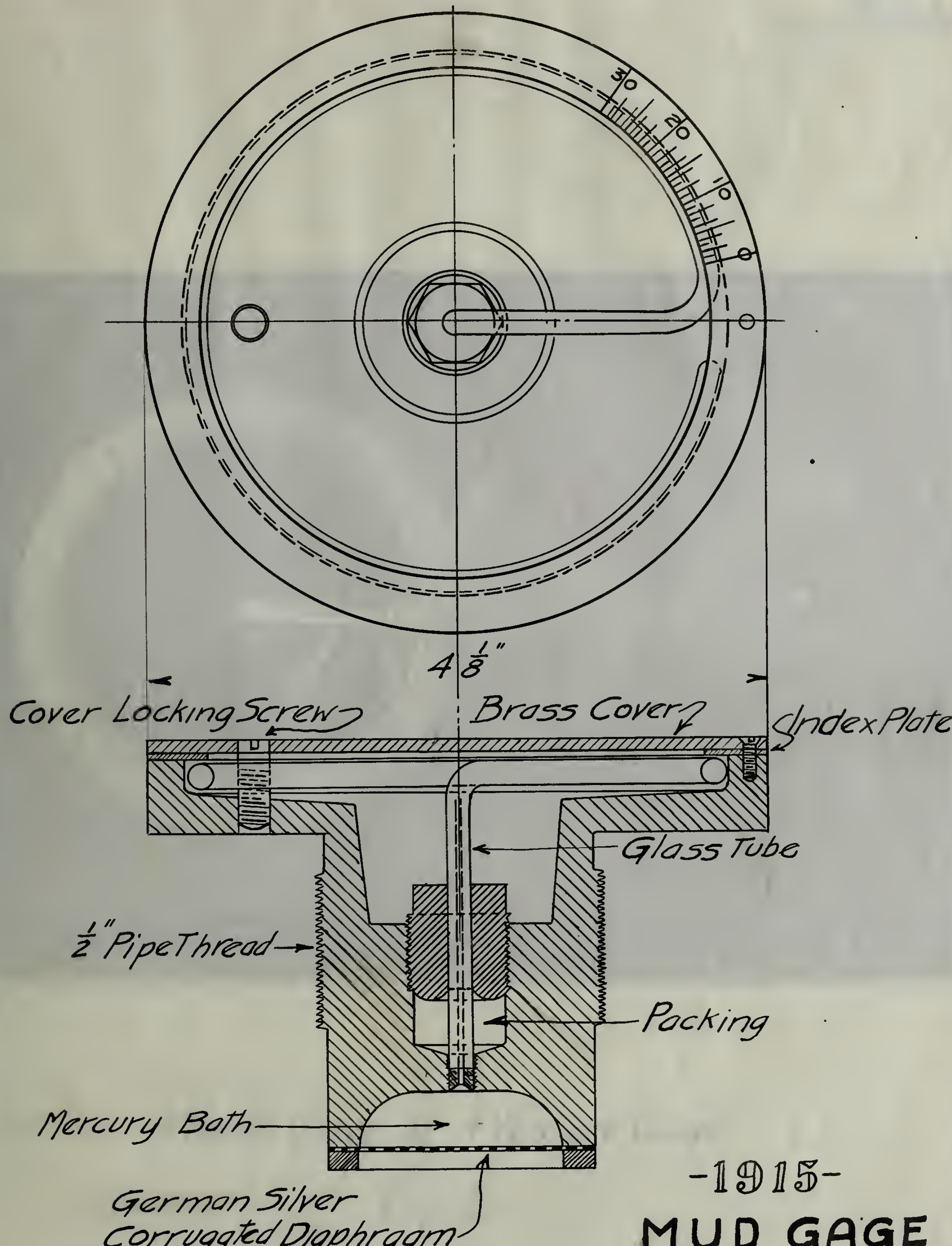
Diagram Showing Position of Gauges in Column Form

Fig. 1a

5. GAGES. The pressure gages were made especially for this work, and were of a type which was successfully used to measure the earth pressures during the construction of the Pennsylvania Tunnels in New York City. Each gage consisted of a flexible German-silver diaphragm acting upon a reservoir containing mercury. The pressure was indicated by the position of the mercury in the tube. The graduation of the tube was arbitrary, so that it was necessary to calibrate it. A thick layer of grease covered the diaphragm during the tests, to protect it from temperature changes and small falling particles. The location of the gages in the column forms is shown in Fig.1a , page 4a. The details of the construction of the gage are shown in Fig. 2, page 6. Fig. 3, page 7, and Fig. 4, page 8, show front and side views of the gage.

6. HEAD INDICATING APPARATUS. A unique method was used for determining the height of concrete in the forms. Brass tubes were set into the forms at one-foot intervals. Wooden plugs fitted with wires and brass screws were set into these tubes. Copper strips wired to electric lamps were fastened over the holes so that the lamps were lighted when the plugs were forced out and made contact. The plugs were kept well oiled so that they would slide easily in the tubes. The arrangement is shown in detail in Fig. 5, page 9.

7. POURING TOWER.. A wooden tower supported the hopper and braced the column form, see Fig. 6, page 10. A sheet-iron funnel was used to direct the concrete from the bottom-dump bucket to the center of the form. The funnel was easily removed, so that the form could be lifted at the end of each test in order to remove



-1915-

MUD GAGE

THESIS WORK.

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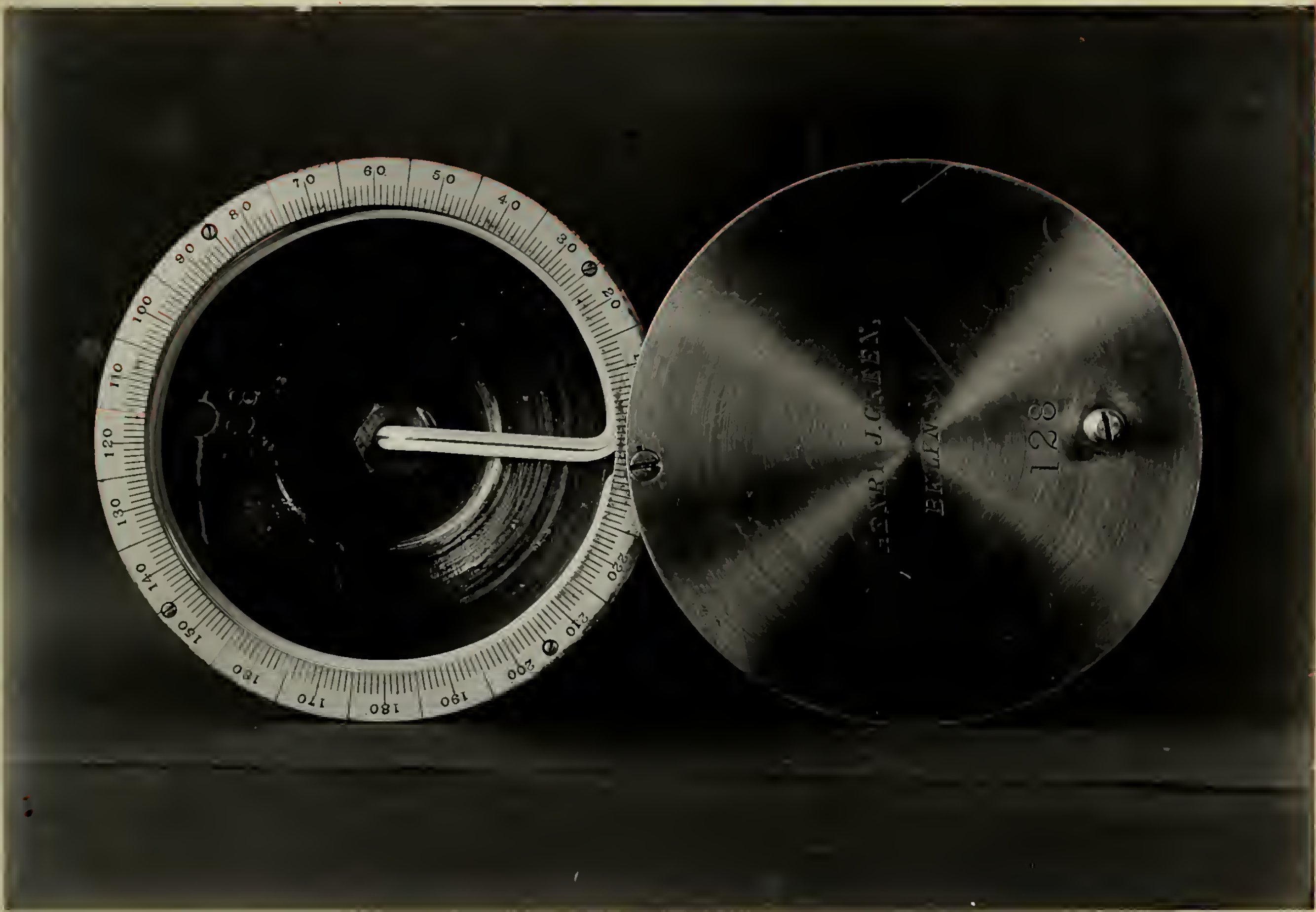
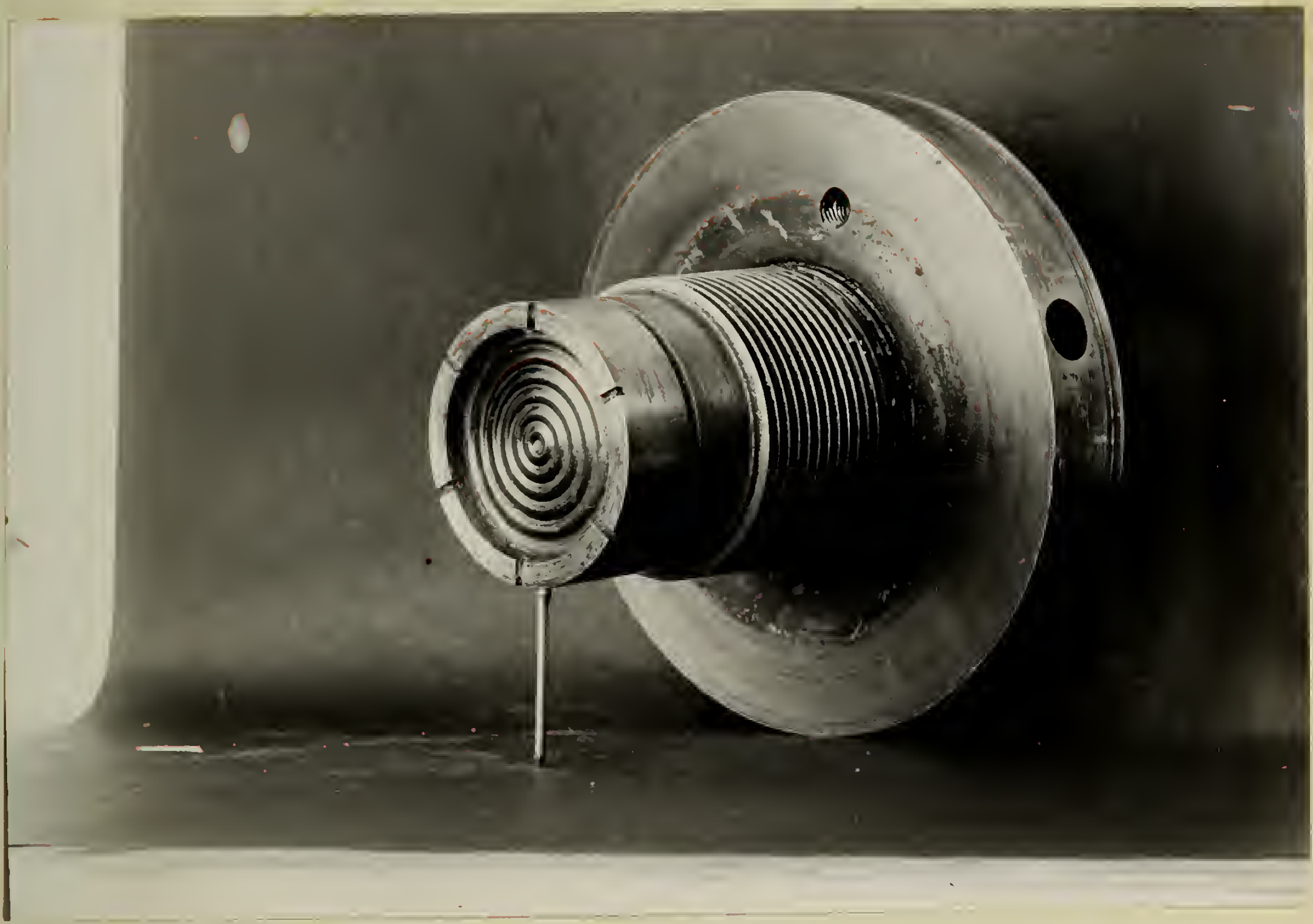
Fig. 2



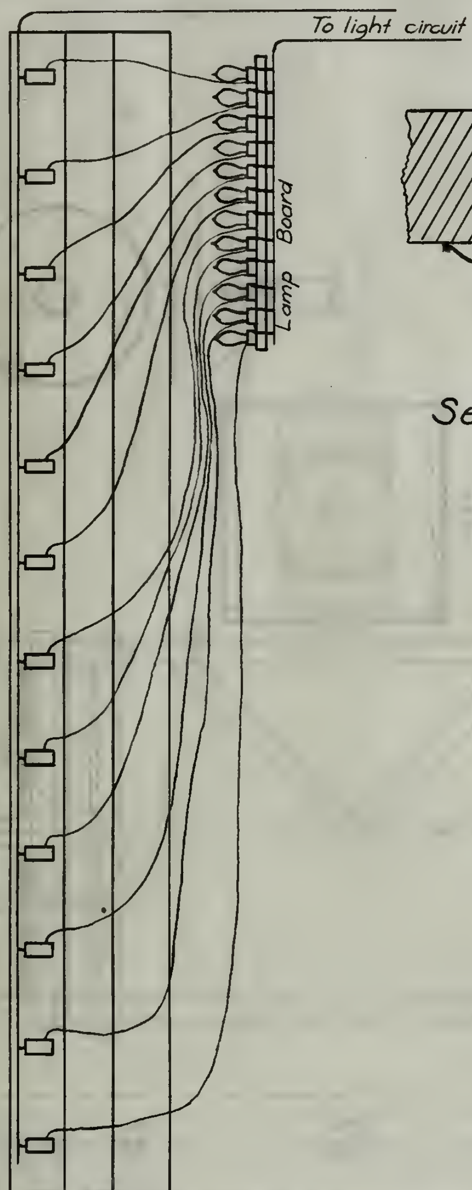
Front View of Pressure Gage

Fig. 3

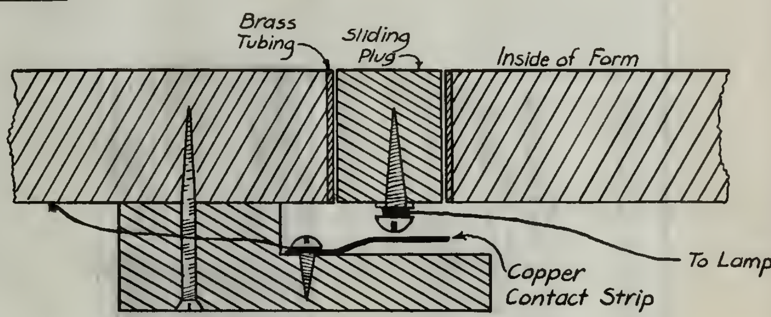


Rear View of Pressure Gage

Fig. 4

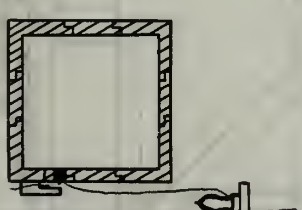


Elevation of Form Showing Wiring



Section of Form thru Sliding Plug

Elevation of Above



Plan of Form

ELECTRICAL HEAD INDICATING APPARATUS

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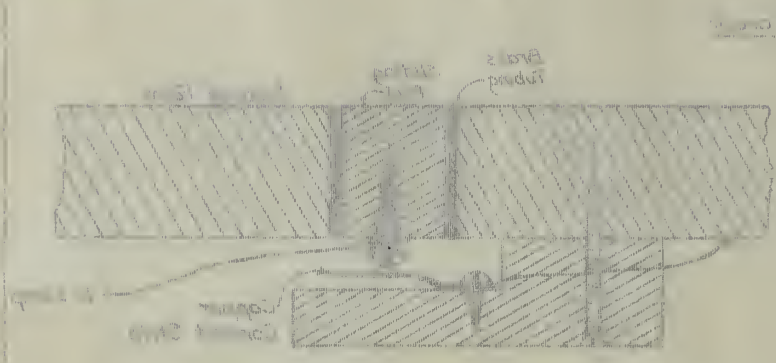
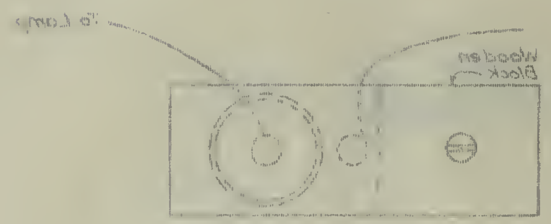
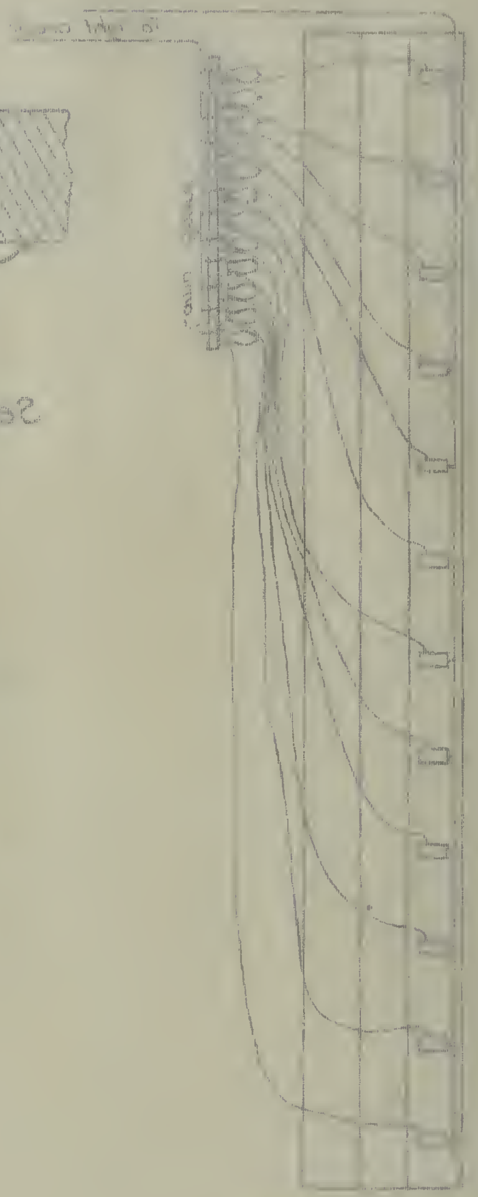
Fig. 5



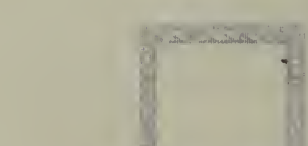
Section of Form thru String Plug



Elevation of Above



Elevation of Form Showing Wiring



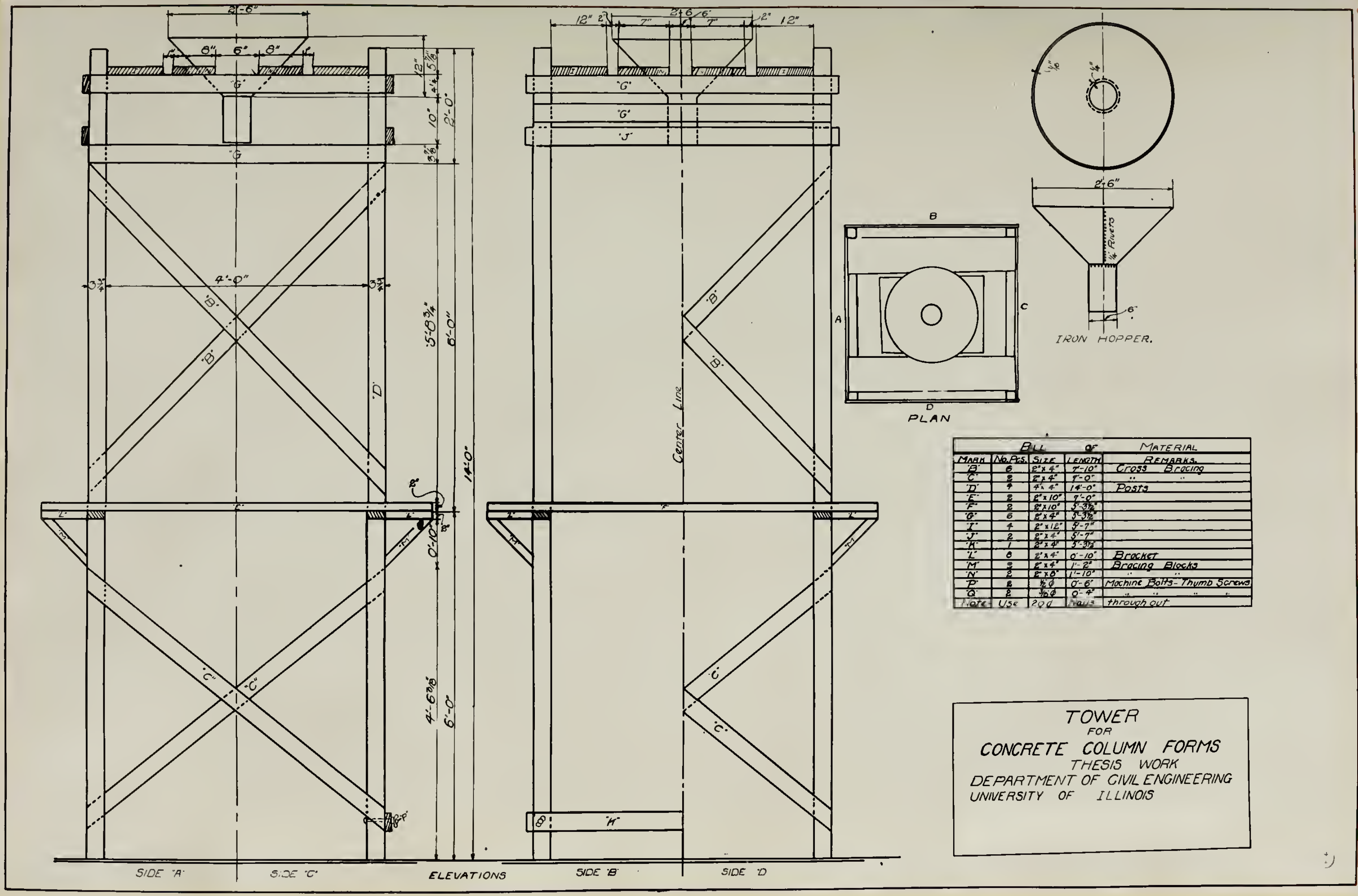
Plan of Form

ELECTRICAL HEAD INDICATING APPARATUS

THESIS - 1915

Fogg, Green, Norris, Randall

Fig. 5



BILL OF				MATERIAL
MARK	No. PCS.	SIZE	LENGTH	REMARKS.
'B'	6	2"x 4"	7'-10"	Cross Bracing
'C'	2	2"x 4"	7'-0"	" "
'D'	4	4"x 4"	14'-0"	Posts
'E'	2	2"x 10"	7'-0"	
'F'	2	2"x 10"	5'-3½"	
'G'	6	2"x 4"	5'-3½"	
'I'	4	2"x 12"	5'-7"	
'J'	2	2"x 4"	5'-7"	
'K'	1	2"x 4"	5'-3½"	
'L'	6	2"x 4"	0'-10"	Bracket
'M'	2	2"x 4"	1'-2"	Bracing Blocks
'N'	2	2"x 6"	1'-10"	" "
'P'	2	½"⌀	0'-6"	Machine Bolts - Thumb Screws
'Q'	2	⅜"⌀	0'-4"	" " " "
Note:	Use	20d	Nails	through out

TOWER
FOR
CONCRETE COLUMN FORMS
THESIS WORK
DEPARTMENT OF CIVIL ENGINEERING
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Fig. 6.

the concrete before it had set. Fig. 7, page 12, shows the arrangement of the column and bucket.

8. BUCKET. The bucket was of the bottom-dump type, and was constructed of sheet steel. The original capacity was 18 cu. ft., but was increased to 48. cu. ft. by building a wooden extension on top. The bucket was elevated and transported by a 5-ton hand-power traveling crane.

III. MATERIALS FOR CONCRETE.

9. Ingredients. The materials were the same as for other experiment work in concrete made by the Engineering Experiment Station. The quality of the materials may be considered as representative of that used in first class concrete work in the central states.

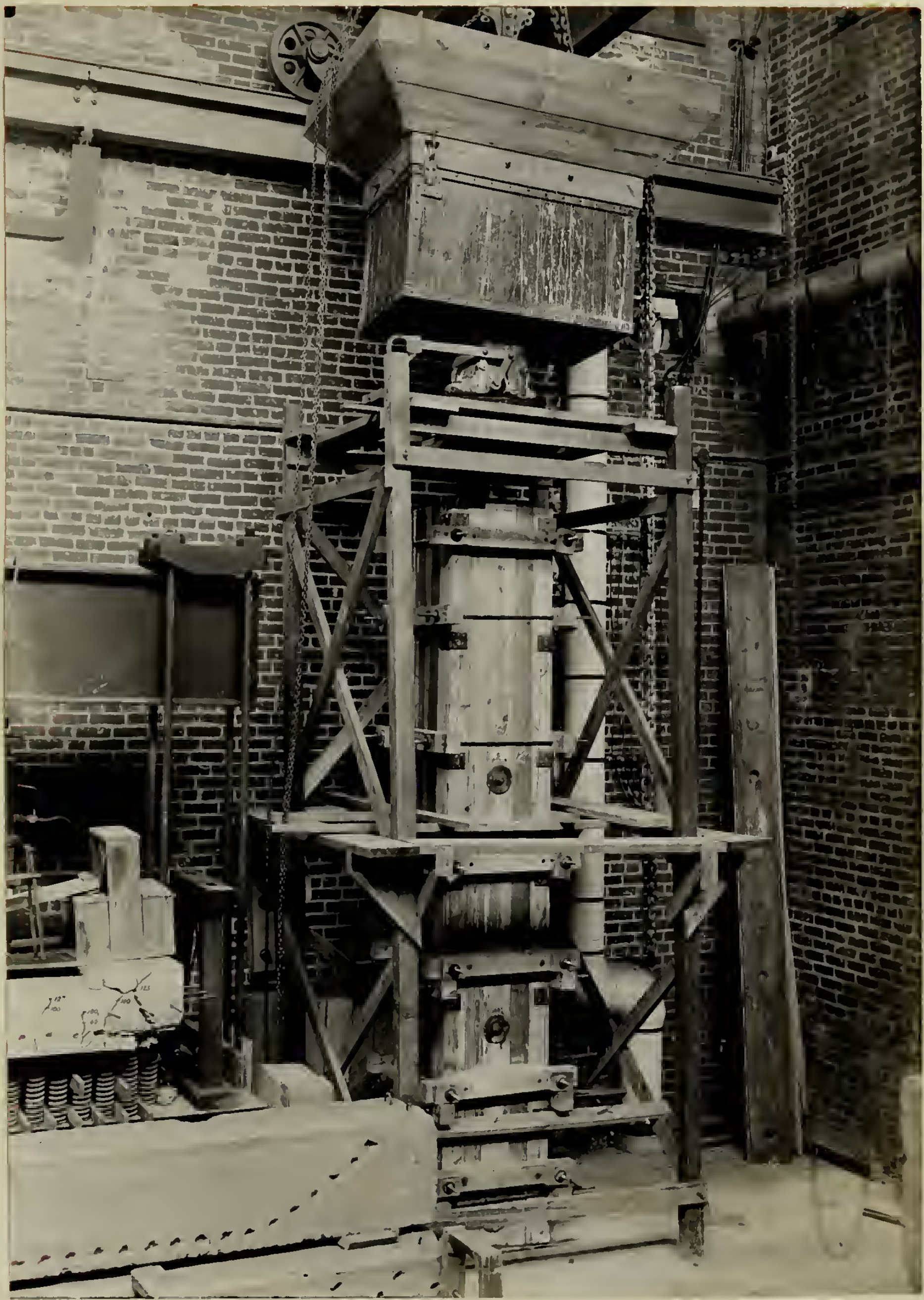
Cement. The cement was Universal Portland. It conformed, except as noted hereafter, to the standard specifications of the American Society for Testing Materials.

The fineness was 94.5% on a No. 100 sieve, and 78.2% on a No. 200 sieve. Data for this test are shown in Table 1, page 14.

A plasticity test gave 23.5% water for normal consistency. The details are shown in Table 2, page 14.

Two neat cement pats, one placed in water and the other in air for 28 days, showed no distortion, radial cracks, or discoloration, and hence it was concluded that the cement was sound.

Twelve neat cement briquettes and eight of 1:3 mortar were tested. The results are given in Table 3, page 15, and Table 4, page 16. The low values shown by these tests are due to the age of the cement which had been stored for over two years.



General View of Column Form, Tower, and Skip.

Fig. 7

The concrete for each test was weighed. The results are given in Table 5, page 18.

Sand. The sand came from a deposit of glacial drift near the Wabash River at Attica, Indiana. It was clean and well graded. The results of the fineness test are given in Table 6, page 19, and in Fig. 12, page 20.

Stone. The stone was crushed limestone from Kankakee, Illinois. It had been previously passed through a one-inch screen and over a quarter-inch screeen. The results of a sieve analysis are given in Table 7, page 19.

10. MAKING THE CONCRETE. The ingredients for the concrete were proportioned by volume. A 1:2:4 mixture was used in all the tests. The concrete was mixed in a one-third cubic yard motor-driven batch mixer, shown in Fig. 9, page 21. The amounts of materials used in a batch are given in Table 8, page 22. For the four tests for the 12-inch columns (Tests 1-4) the concrete was mixed in two batches, the first being dumped onto the floor and later incorporated with the second batch. For the three tests for the 2o-inch columns (Tests 5-7) three batches were necessary. The material was dumped from the mixer onto the concrete mixing floor and was then shoveled into the skip. The skip was then raised by a traveling crane and moved into position over the column form (see Fig. 7, page 12). In a few cases the concrete was used twice, in consecutive tests; and in these cases it was thoroughly sprinkled and re-mixed before being re-loaded into the skip.

After the concrete was mixed preparatory to the pressure tests, sample cylinders were molded and tested to determine the crushing strength of the concrete.

Table 1.

Fineness of Universal Portland Cement.

Amount of Cement used...........................	1000 units
Amount left on 200 mesh sieve..................	215 units
Amount left on 100 mesh sieve..................	55 units
Checked weight..................................	995 units

	Experiment	Standard
Amount retained on 200 mesh sieve.....	21.5%	25.0%
Amount retained on 100 mesh sieve.....	5.5%	8.0%

Table 2.

Plasticity of Universal Portland Cement.

No. of Test.	Amount of Water.	Amount of Water.	Penetration.
	c.c.	%	mm.
1	115	23.0	9.5
2	118	23.5	9.5
3	120	24.0	9.8

Temperature of Room .... 25.0 C.

Temperature of Water ... 22.0 C.

Table 3.

TENSILE STRENGTH

Neat Briquettes.

Briquette No.	Age when Tested.	Tensile Strength.	Standard.
	Days	lbs. per sq. in.	
1	1	265	
2	1	260	
3	1	265	
4	1	230	
		Average 255.0	175.
5	7	578	
6	7	447	
7	7	552	
8	7	445	
		Average 480.5	500
9	60	635	
10	60	700	
11	60	745	
12	60	540	
		Average 652.5	600

[illegible]

Table 4.

TENSILE STRENGTH

1:3 Briquettes

Briquette No.	Age when Tested.	Tensile Strength.	Standard.
	Days	lbs. per sq. in.	
13	7	164	
14	7	177	
15	7	155	
16	7	148	
		Average 161.0	200
17	60	245	
18	60	270	
19	60	220	
20	60	180	
		Average 228.8	275

Three cylinders eight inches in diameter and sixteen inches high were made from the concrete for each pressure test. They were covered with damp cloths during the setting period of three days. The forms were then removed and the specimens placed in a bed of damp sand for 25 days. A plaster of paris cap was applied to each end of the cylinder and allowed to set for a few hours before testing so as to secure an even distribution of the load.

Each cylinder was tested in a Riehle machine of 100,000 pounds capacity. The results of the test are given in Table 9, page 24.

IV. METHOD OF MAKING TESTS.

11. CALIBRATION OF GAGES. The gage tester used in calibrating the pressure gages is shown in Figs. 10 and 11, pages 25 and 26. Bourdon Gage No. 458 was calibrated with a Crosby Gage Tester and then was connected to the end of the gage tester to which the pressure gages were attached. The gage tester was connected to the standpipe in the Hydraulic Laboratory, and a static pressure of 20 lbs. per sq. in. applied. This pressure was lowered a pound at a time by lowering the level of the water in the standpipe.

The gages were calibrated before each pressure test. The temperatures of the air and water were taken during each calibration. All the gages were read simultaneously for each change in pressure, and the readings were recorded. For the data and

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

Table 5.

WEIGHT OF CONCRETE.

Test No.	Weight per Cubic Foot. lbs.
1	139.5
2	138.5
3	138.5
4	139.0
5	141.0
6	141.0
7	140.2

[illegible]

[illegible]

[illegible]

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Table 6

Sieve Analysis of Sand.

Sieve No.	Dia. Opening	Grams Retained	Grams Passing	Per Cent Passing
--	.20	74.3	925.7	92.6
5	.16	117.0	808.7	80.9
10	.073	261.8	547.0	54.7
16	.042	205.0	342.0	34.2
20	.034	35.5	306.6	30.7
30	.022	101.0	205.6	20.6
40	.015	101.8	103.9	10.4
60	.009	71.0	32.9	3.3
74	.0078	14.7	18.3	1.8
150	.0033	10.0	8.3	.8
Pan.	---	8.3	0.0	.0
		1000.4		

Table 7.

Sieve Analysis of Stone.

Dia. Opening	Grams Retained	Grams Passing	Per Cent Passing
1.00			
.67	159.3	840.6	84.1
.50	80.3	760.3	76.0
.45	127.5	632.7	63.3
.30	278.7	353.9	35.4
.16	174.5	179.3	17.9
.073	62.0	117.3	11.7
Pan	117.3	000.0	00.0

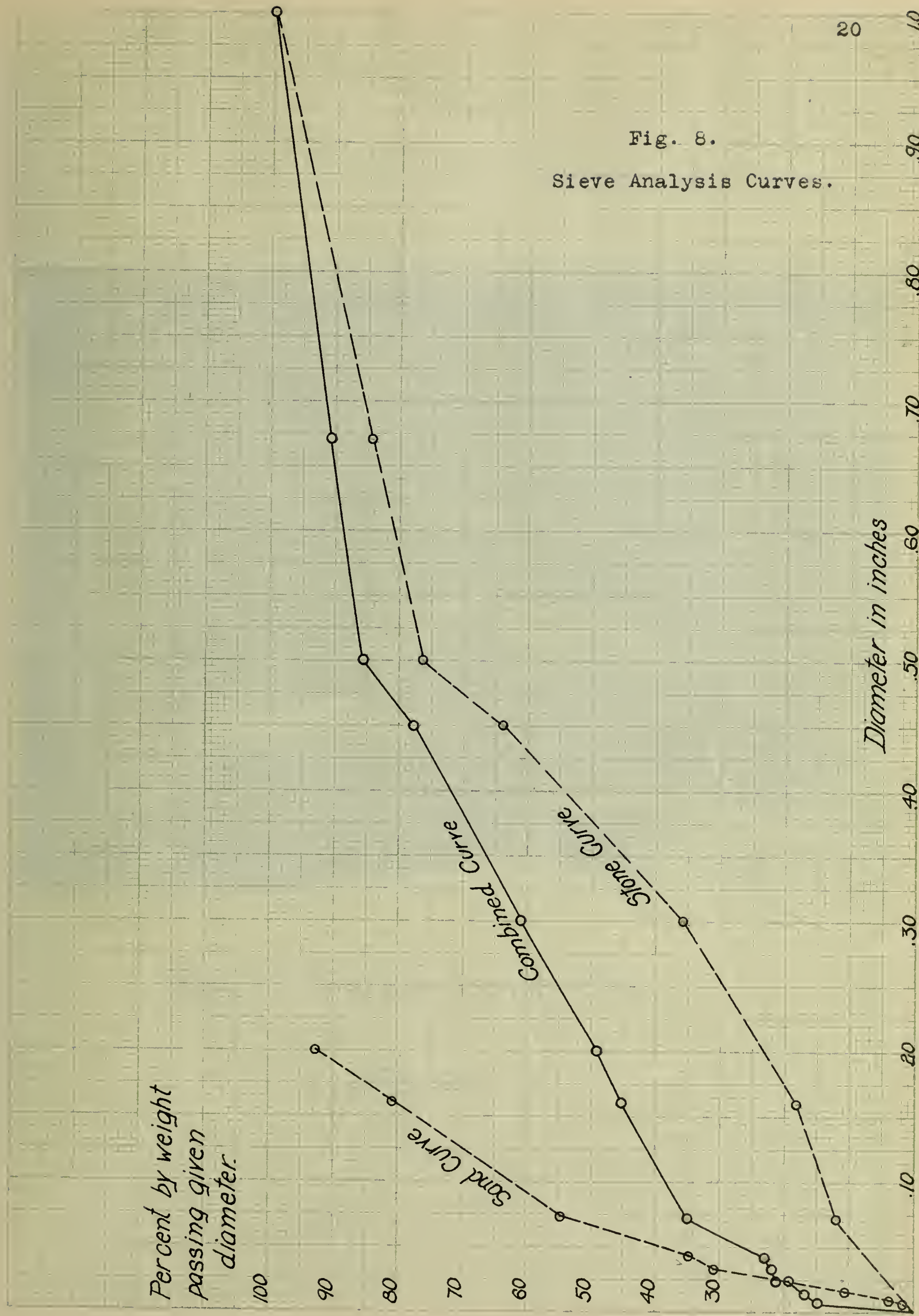


Fig. 8.

Sieve Analysis Curves.

View of Concrete Mixing Plant.

Fig. 9

Table 8

MATERIALS IN ONE BATCH FOR 12-INCH COLUMNS.

Material	Quantity	Weight lbs.
Stone	12 bucketfuls @ 42 lb.	384
Sand	6 bucketfuls @ 52 lb.	312
Cement		141
Water		120

Two batches were used in each test.

MATERIALS IN ONE BATCH FOR 20-INCH COLUMNS.

Material	Quantity	Weight lbs.
Stone	22 buckets @ 42 lb.	924
Sand	11 buckets @ 52 lb.	572
Cement		235
Water		198

Three batches were used in each test.

results see Tables 10 to 17, pages 27 - 33, and Figs. 13 - 17, pages 35 - 39.

Two preliminary tests were made of the Bourdon gage on the Crosby Gage Tester, and two preliminary tests of the Bourdon gage with the five pressure gages on the gage tester. After each preliminary test, the pressure was increased to a maximum of about 20 lbs. per sq. in. and maintained for a period of 24 hours in order to detect any leakage in the gages or in the connections.

12.MEN REQUIRED. Nine men were employed on each test. One man had general supervision of the test, and gave gong signals for the reading of the gages. One man noted the time at which the electric lamps were lighted by the forcing out of the contact plugs. Five observers read the gages. One assistant manipulated the gate at the bottom of the skip and another in the skip kept the flow uniform through the gate.

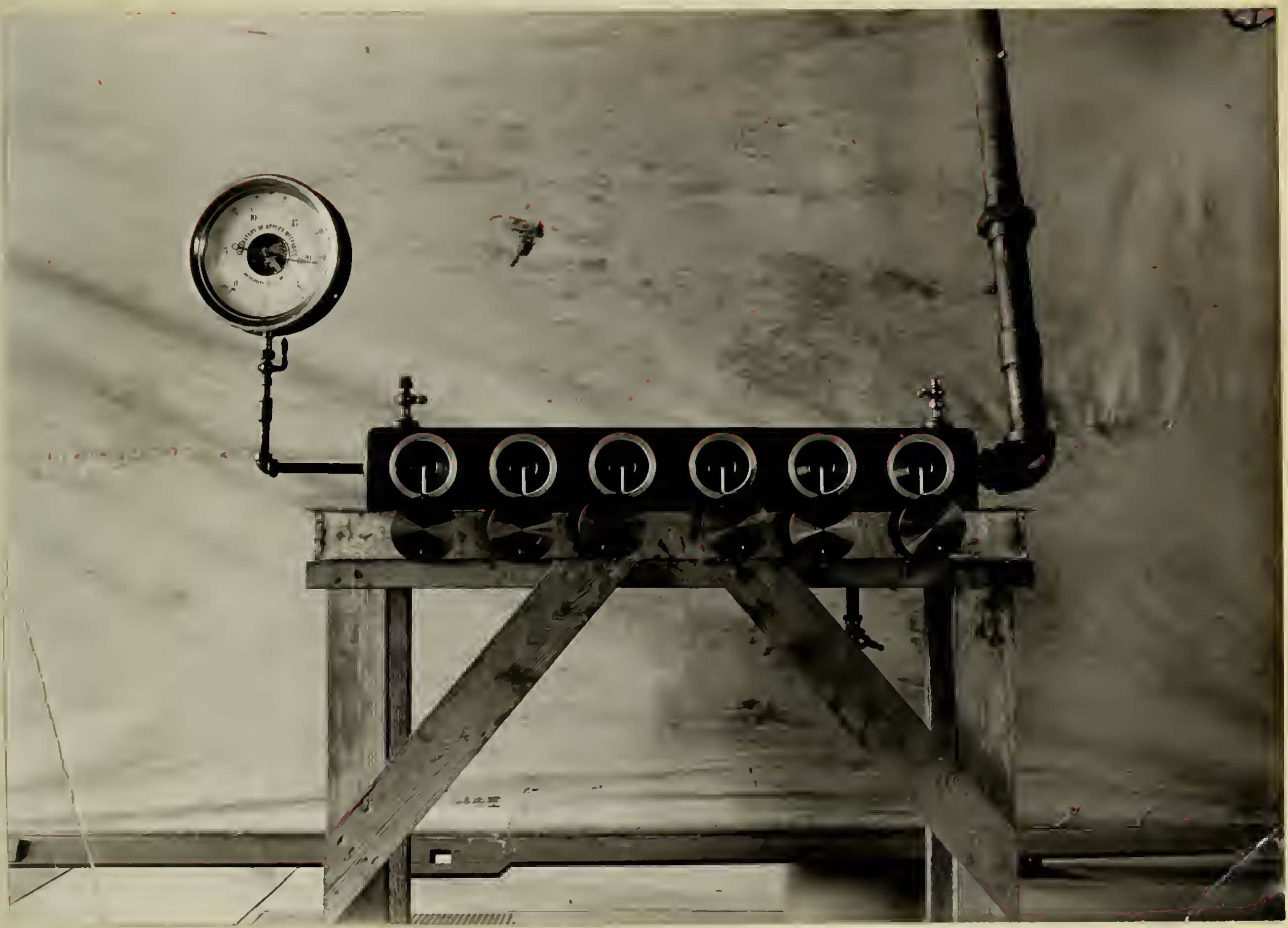
13. METHODS OF POURING. Four tests were made on a 12-inch square column form and three on a 20-inch square column form. Two methods of pouring the concrete were used: the continuous, and the intermittent methods.

In the continuous method, the gate at the bottom of the skip was opened far enough to secure a continuous flow of concrete through the hopper into the form. A gong was struck every fifteen seconds, and the highest pressure reading during the interval was recorded by an observer at each gage. Three tests were made on the 12-inch size and two tests on the 20-inch size column forms were made by this method.

Table 9.

. COMPRESSIVE STRENGTH OF CYLINDERS.

Test No.	Cyl. No.	Age at Test. days.	Area sq.in.	Maximum Load lbs.	Load lbs. per sq. in.	Average Load.
	1	30	49.39	32800	665	
1	2	30	50.64	37070	733	
	3	30	50.77	31350	618	
						672
	1	30	50.26	58500	1165	
2 & 3	2	30	50.26	56900	1130	
	3	30	50.26	44700	890	
						1098
	1	30	50.26	44000	876	
4	2	30	49.50	55800	1126	
	3	30	50.26	49500	986	
						996
	1	30	50.26	56800	1130	
5 & 6	2	30	50.26	56900	1130	
	3	30	50.26	56400	1120	
						1127
	1	60	51.15	52460	1025	
7	2	60	52.80	52040	1005	
	3	60	49.00	41000	836	
						955



Gage Calibration Apparatus.

Fig. 10

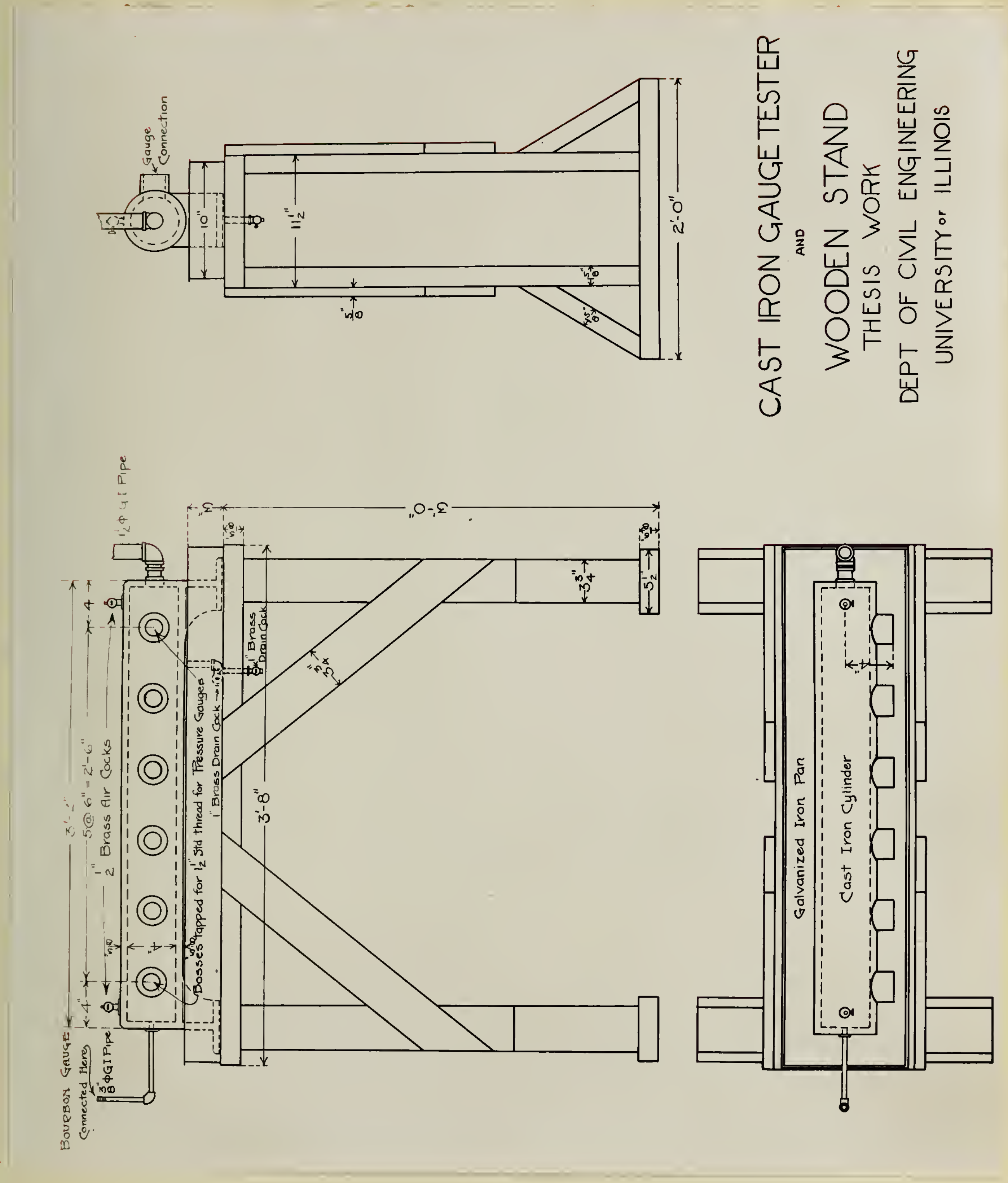

CAST IRON GAUGE TESTER
AND
WOODEN STAND
THESIS WORK
DEPT OF CIVIL ENGINEERING
UNIVERSITY OF ILLINOIS
Gauge Connection
10"
11 1/2"
2'-0"
3'-0"
3'-8"
3'-2"
5@ 6" = 2'-6"
1/2" Brass Air Cocks
Bosses Tapped for 1 1/2" Std thread for Pressure Gauges
1" Brass Drain Cock
1" Brass Drain Cock
Bourbon Gauge Connected Here
3/8" ΦGI Pipe
1 1/2" Φ G I Pipe
Galvanized Iron Pan
Cast Iron Cylinder

Fig. 11

Table 10.

CALIBRATION OF BOURDON GAGE NO. 458.

Area of Piston, 0.2 sq. in.
Weight of Piston, 1 lb.

November 5, 1914.

Reading No.	Total Applied Load lbs.	Gage Reading lbs.per sq. in.	Reading No.	Total Applied Load lbs.	Gage Reading lbs.per sq. in.
1	1	4.9	16	1	5.1
2	1.5	7.4	17	1.5	7.5
3	2	9.9	18	2	10.
4	2.5	12.3	19	2.5	12.4
5	3	14.8	20	3	14.8
6	3.5	17.4	21	3.5	17.3
7	4	19.7	22	4	19.7
8	4.5	22.4	23	4.5	22.4
9	4	19.7	24	4	19.7
10	3.5	17.3	25	3.5	17.4
11	3	14.8	26	3	14.7
12	2.5	12.3	27	2.5	12.3
13	2	10	28	2	10.
14	1.5	7.5	29	1.5	7.5
15	1	5.1	30	1	5.

Table 11.

CALIBRATION OF GAGES.

November 5, 1914.

Reading No.	No. 458 lbs.per sq. un.	Altitude Gage ft.	No. 127	No. 128	No. 129	No. 130.
1	21.2	51.5	126	139	83.5	107.
2	20.8	51.5	125.5	138.8	83.1	106.7
3	20	49.5	124.5	137.6	81.3	106.3
4	19	47	122.5	135.5	77	101.5
5	18	44	121.5	134	73.3	99
6	17.1	42	119	132	70.3	95
7	16.1	39.5	117	129.2	67	91.5
8	15.1	37.5	116	127.2	65	88.5
9	14	35	113.5	125	60.6	85.3
10	13	33	111	122.3	54	80.8
11	12	30.5	109	120.2	48.2	77
12	11	28	107.2	117.2	43.5	71.5
13	10	26	104.8	115	38	68
14	9	24	102.5	111.3	33.5	63
15	8	22	100	108.5	28.6	58.8
16	7	18.5	97.7	105	21.7	54.1
17	6	16	95	102	16.1	50.2
18	5	14	92.6	98.8	10.2	46.3
19	4	11	89.5	95.4	5.3	42
20	3.1	9.5	88.2	92.4		38.5
21	2.6	9	81	89.8		34.2
22	0		81	80.7		21.9

Temperature of Room, 73.5 degrees F.

Table 12.

CALIBRATION OF GAGES.

November 6, 1914.

Reading No.	No. 458 lbs. per sq. in.	Altitude Gage ft.	No. 127	No. 128	No. 129	No. 130
1	21	52	126	139.2	84.6	108
2	20	49.9	124.5	139	82.8	105.4
3	19	47.4	122.7	136	78.8	102
4	18	44.6	121	134	74	98.8
5	16.9	42.3	119	131.4	71.2	95.5
6	15.8	40	117.2	129.5	65.5	92.2
7	14.9	38.5	116	127.5	62.5	88.6
8	14	36	114	125	60.5	85.5
9	13	33.6	112	123.4	52.2	81.2
10	11.1	29.3	108.2	118.5	43.5	73.4
11	10	27.4	106.2	115.8	37.6	69.6
12	9	25.4	104	113.	33	64.8
13	8	23	101.4	110	28.2	61.5
14	7	20.5	99	106.6	20.8	56
15	6	17.7	96.8	103.5	16	51.8
16	5	15.7	94.2	99.6	10.5	47
17	4	12.8	90.8	95.5	1.5	43
18	3	10.8	89.2	93		39
19	2		85.5	88		31.8
20	1		84	85.5		27.8
21	0		82	82.2		22

Temperature of Air, 83 degrees F.

Temperature of Water, 79 degrees F.

Table 13.

CALIBRATION OF GAGES.

December 4, 1914.

Reading No.	No. 458 lbs.per sq. in.	Altitude Gage ft.	No. 127	No. 128	No. 129	No. 130
1	20.5	50.5	125.8	139.4	82	107.2
2	20	48.5	125.2	139.5	82	107
3	19	47	123.5	138.4	77.5	103.5
4	18	44	122	136	72	99.6
5	17	42	119.6	133.4	70	96.2
6	16	40	117.6	131.7	65.2	92.8
7	15	37.7	116	129.8	62	89.5
8	14	35.2	113.8	126.9	59.5	85.4
9	12.9	32.8	111.8	124.2	51.2	81.6
10	12	30	109.5	121.5	46.2	77.5
11	11	28	107.8	119.5	42	74
12	10	26.5	105.4	116.3	36.5	69.8
13	9	23.7	103.2	113.3	33.3	65
14	8	22.2	101.4	110.3	29.9	61.4
15	7	18.8	98.8	107.1	24.5	56
16	6	16.1	96.2	105.2	19.5	52.2
17	5	14.5	94.3	102	14.6	48
18	4	12.9	91.8	100.4	9.9	43.3
19	3	9.9	89.3	97	6	39.5
20	2		86	90	2	32.4
21	1		85	90		29

Temperature of Air, 69.5 degrees F.

Temperature of Water, 69.5 degrees F.

Table 14.

CALIBRATION OF GAGES.

December 10, 1914.

Reading No.	No. 458 lbs.per sq. in.	Altitude Gage, ft.	No. 127	No. 128	No. 129	No. 130
1	0		80.7	87		20.6
2	22.8	54.8	129.2	143.5	88	113.8
3	22	53	127.8	142.5	85.4	111.6
4	21	51	126.7	140.9	82.9	108.9
5	20	48.5	125	139.2	80	106.4
6	19	46.5	123.2	137.3	76.3	103.1
7	18	43.8	122	136.3	72	100.8
8	17	41.5	119.8	133.8	69.3	96.2
9	16	39.7	118	131.2	65	93
10	15	37.2	116.2	129.3	61	90
11	14	35	114.5	127.7	55.1	86.5
12	13	32.8	112.1	124.9	49.8	82.2
13	12	30.4	110	122.1	45.3	78
14	11	28.2	108.2	119.9	41	74.3
15	10	26.2	106	117.2	36	69.1
16	9	23.2	103.8	114.5	32.1	66
17	8	21.5	101.8	111.1	28.7	62.4
18	7	18.2	99.6	108.8	23.1	57.2
19	6	16	97.1	105.9	17.5	54.2
20	5	14	94.5	102.9	14.7	49.3
21	4	11.2	92.2	100.6	8.7	44.8
22	3	9.2	89.9	97.8	2	40.1
23	2		87.2	92.6		34.9
24	1		84.3	91.1		29
25	0		82.7	87.6		25

Temperature of Air, 66 degrees F.

Temperature of Water, 68 degrees F.

Table 15.

CALIBRATION OF GAGES.

December 12, 1914.

Reading No.	No. 458 lbs.per sq. in.	Altitude Gage, ft.	No. 127	No. 128	No. 129	No. 130
1	0		82	86.4	-3	23
2	22.8	55.7	130.1	143.5	90	114.5
3	22	53.8	129.2	143.5	87.8	113
4	20.9	51.5	127.3	142.	84	109.5
5	20	49.4	126	140.5	81.5	107.2
6	19	47	124.1	138.5	77.9	104.3
7	18	44.5	122.8	136.5	74	101.5
8	17	42	120.8	134.2	70	97
9	16	40	118.8	133.4	65.2	93.8
10	14.9	36.8	117	130.8	61.8	90.1
11	14	34.6	115.1	128.5	56.2	86.5
12	13	32.4	113	125.6	51.1	83
13	11.9	29.8	111	122.5	46.9	78.5
14	11	27.9	109	121.5	42.2	74.8
15	10	25.7	106.9	118	37.8	71.7
16	9	23.1	104.5	115.4	32.5	66.4
17	7.9	21	102.1	112.3	28.1	63.3
18	7	18.2	100.7	108.8	24.2	57.4
19	6	16.1	98	107.2	18.8	54
20	5	13.8	95.8	104	15.8	50.5
21	4	11	93.2	101	10	45
22	3	9.2	91	98.2	4.8	41.4
23	2		87.8	93.1	2	35
24	1		85.8	91.5	-1	30.8
25	0		83	86.5		25

Temperature of Air, 68.5 degrees F.

Temperature of Water, 72 degrees F.

Table 16.

CALIBRATION OF GAGES.

December 17, 1914.

Reading No.	No. 458 lbs. per sq. in.	Altitude Gage ft.	No. 127	No. 128	No. 129	No. 130
1	0		83	88.5	-18	25
2	23	56	130.5	144.	90.5	116
3	20	49.6	126.2	140.5	81.9	108.9
4	18	44.8	123.1	136.8	74.3	102.2
5	16	40.6	119.8	133.5	65.6	95.8
6	15	38	117.5	131	62	92.1
7	14	35.8	115.7	128.3	55.8	88.2
8	13	33.9	113.5	126.1	51.6	84.9
9	12	31	111.3	123.5	47	80.1
10	11	28.3	109.5	121.7	41.7	77.6
11	10	26.1	107	118.5	36.9	73.4
12	9	23.9	105	115.8	32	68
13	8	21	103.7	112.8	30.3	63.8
14	7	18.1	100	109.3	25.7	59
15	6	17	97.7	107	18.2	55
16	5	15	95	103.2	14.5	50.9
17	4	11.9	92.9	100	8	46
18	3	9.8	90.8	98.5	2	42
19	2		88	93.3	-4	35.9
20	1		85.9	90.8	-8	31.9
21	0		83	87	-20	26

Temperature of Air, 70 degrees F.

Temperature of Water, 68 degrees F.

Table 17.

CALIBRATION OF GAGES.

December 22, 1914.

Reading No.	No. 458 lbs.per sq. in.	Altitude Gage ft.	No. 127	No. 128	No. 129	No. 130
1	19.9	48.5	125.6	140	80	107.8
2	18	44.1	123.5	137	74	102
3	16	39.8	118.9	133.4	65.7	95.6
4	14	35.1	116.2	130	57.1	89
5	12	30.7	111.7	124	47.2	80.8
6	10	27	107.9	119.4	37.6	72.8
7	9	24.2	105.4	116.7	33.8	68.7
8	8	22.6	103	113.7	27.5	63.9
9	6.9	19	100.3	110	22.1	58.9
10	6	17	98.4	107.6	18	55.2
11	5	15.4	96	105.1	14.8	50.7
12	4	12	93.7	102	8	45.9
13	3		91.4	98	2.2	42.
14	2		89	96.4	-1.2	37.5
15	1		86.7	93	-6	32.2
16	0		84	89.2	-12	27

Temperature of Air, 68.5 degrees F.

Temperature of Water, 66 degrees F.

Fig. 13.

Calibration Curve for Bourdon Gage No. 458.

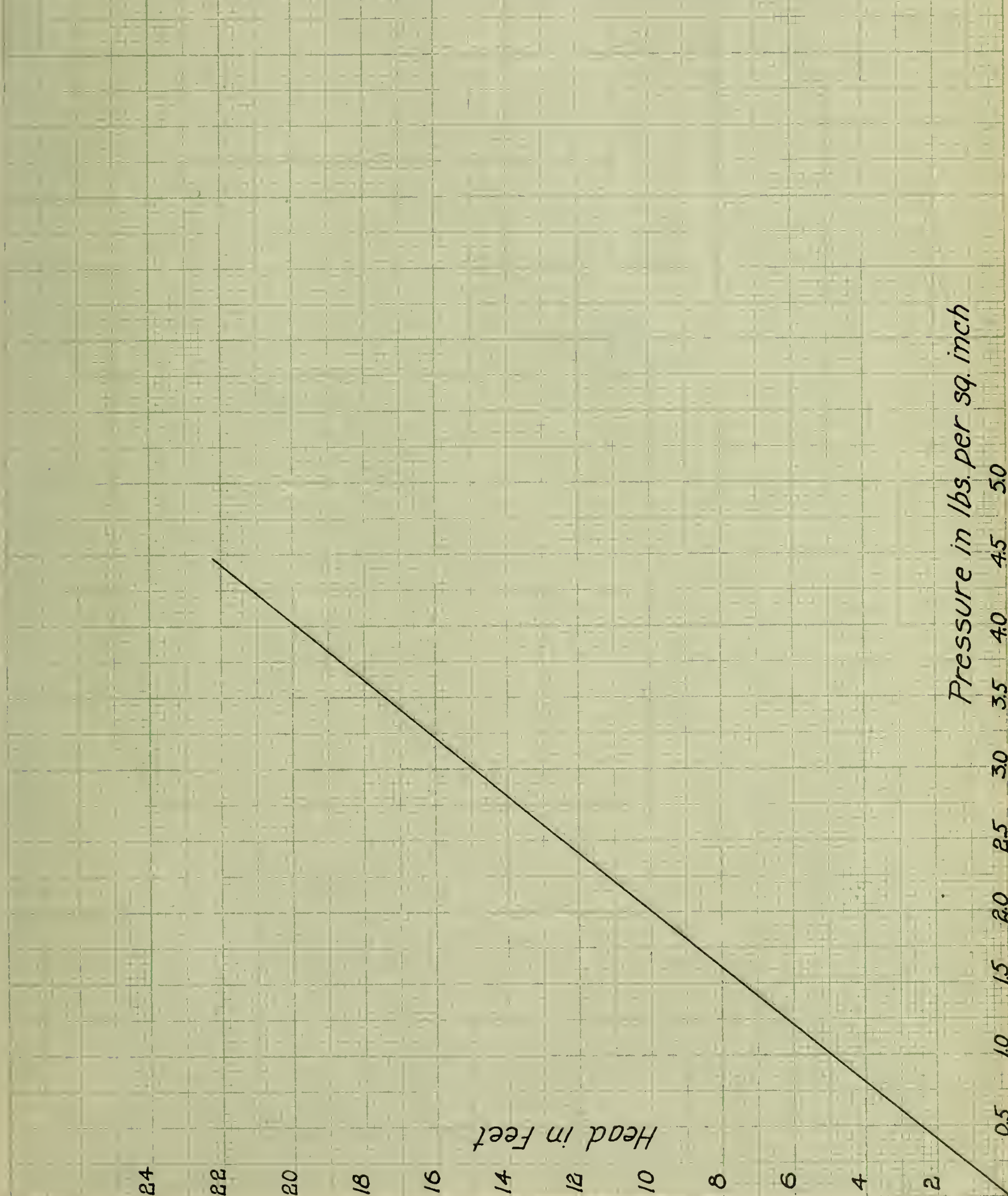


Fig. 14.

Calibration Curves for Gage No. 127.

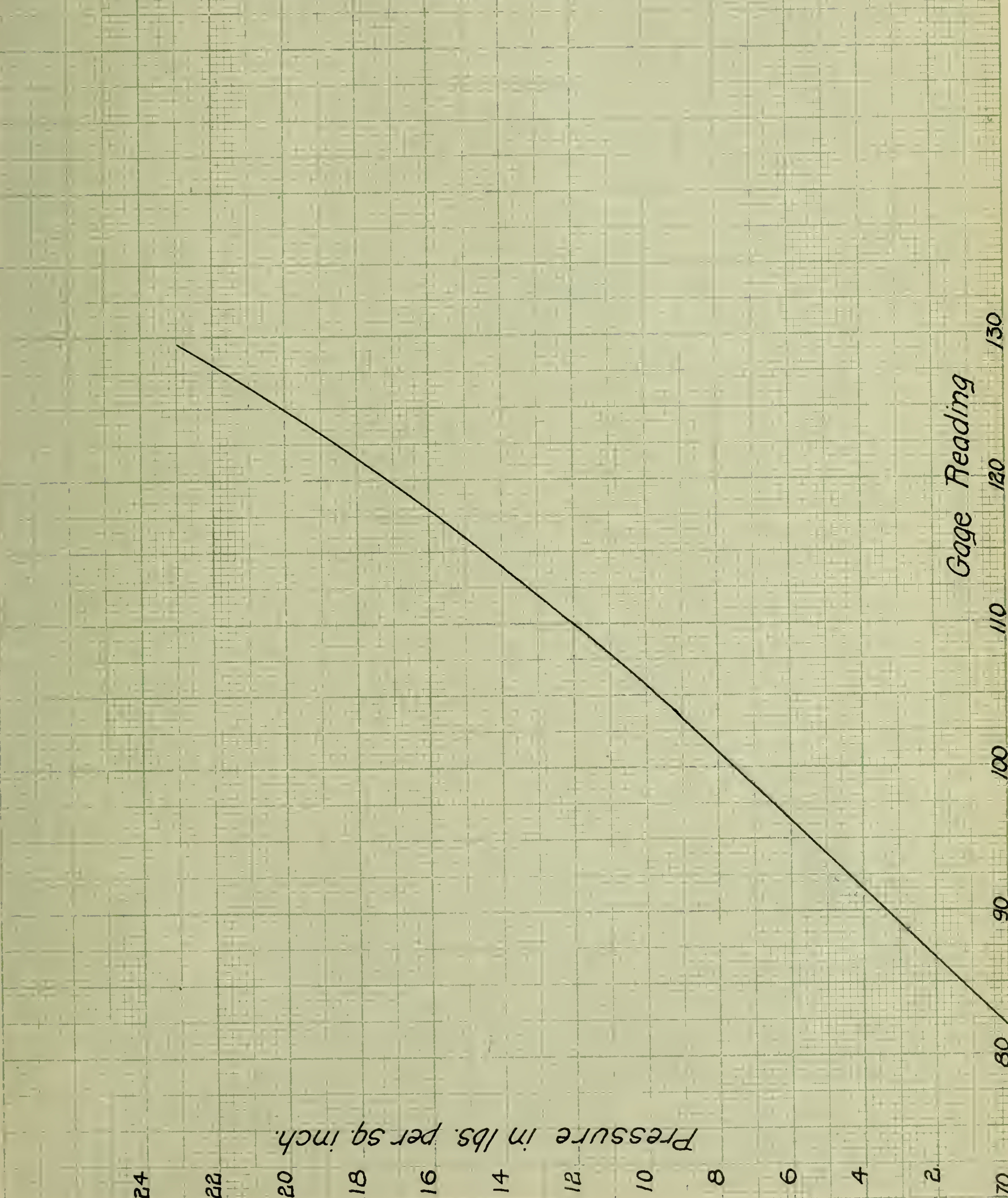


Fig. 15

Calibration Curves for Gage No. 128.

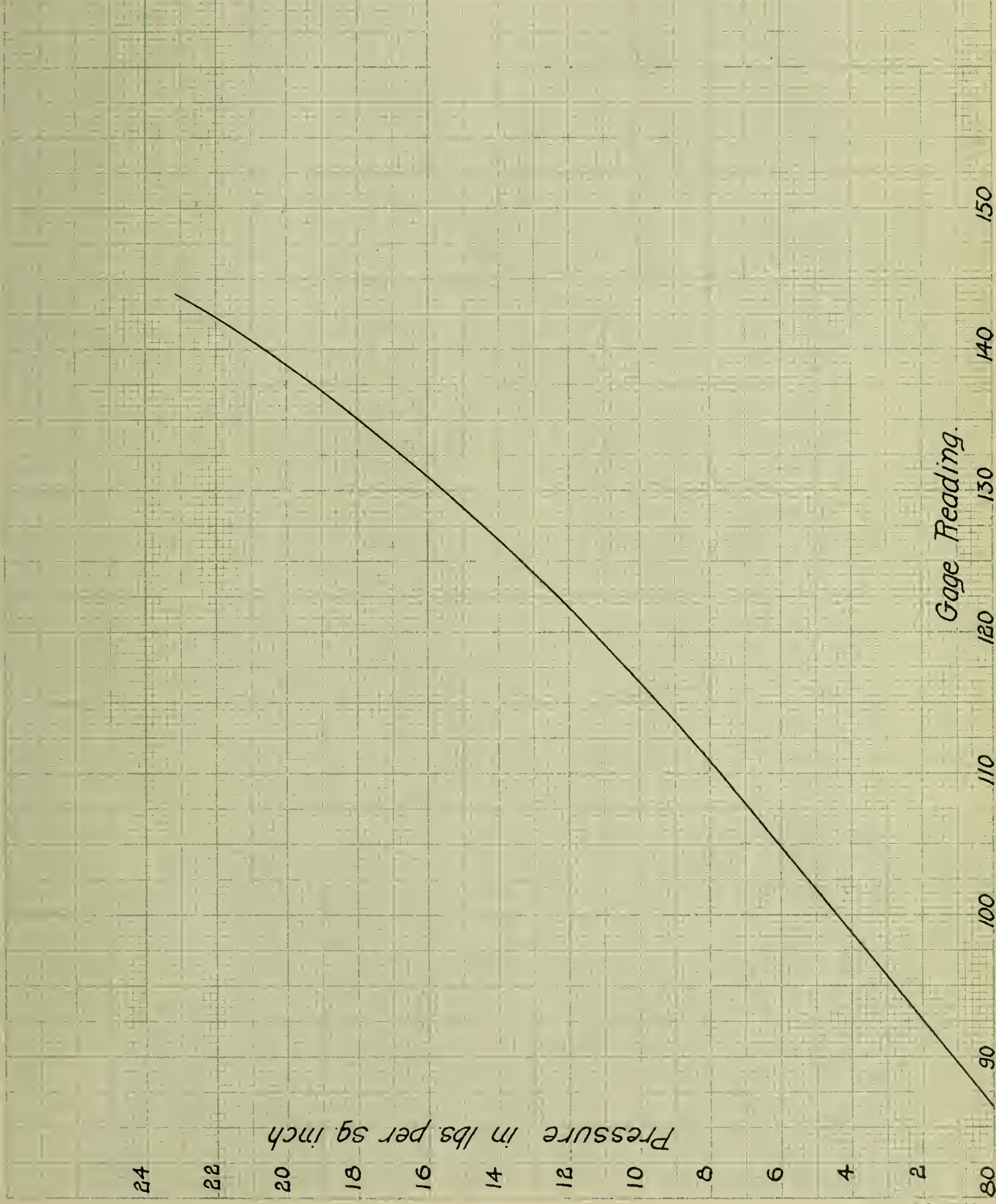


Fig. 16.

Calibration Curves for Gage No. 129.

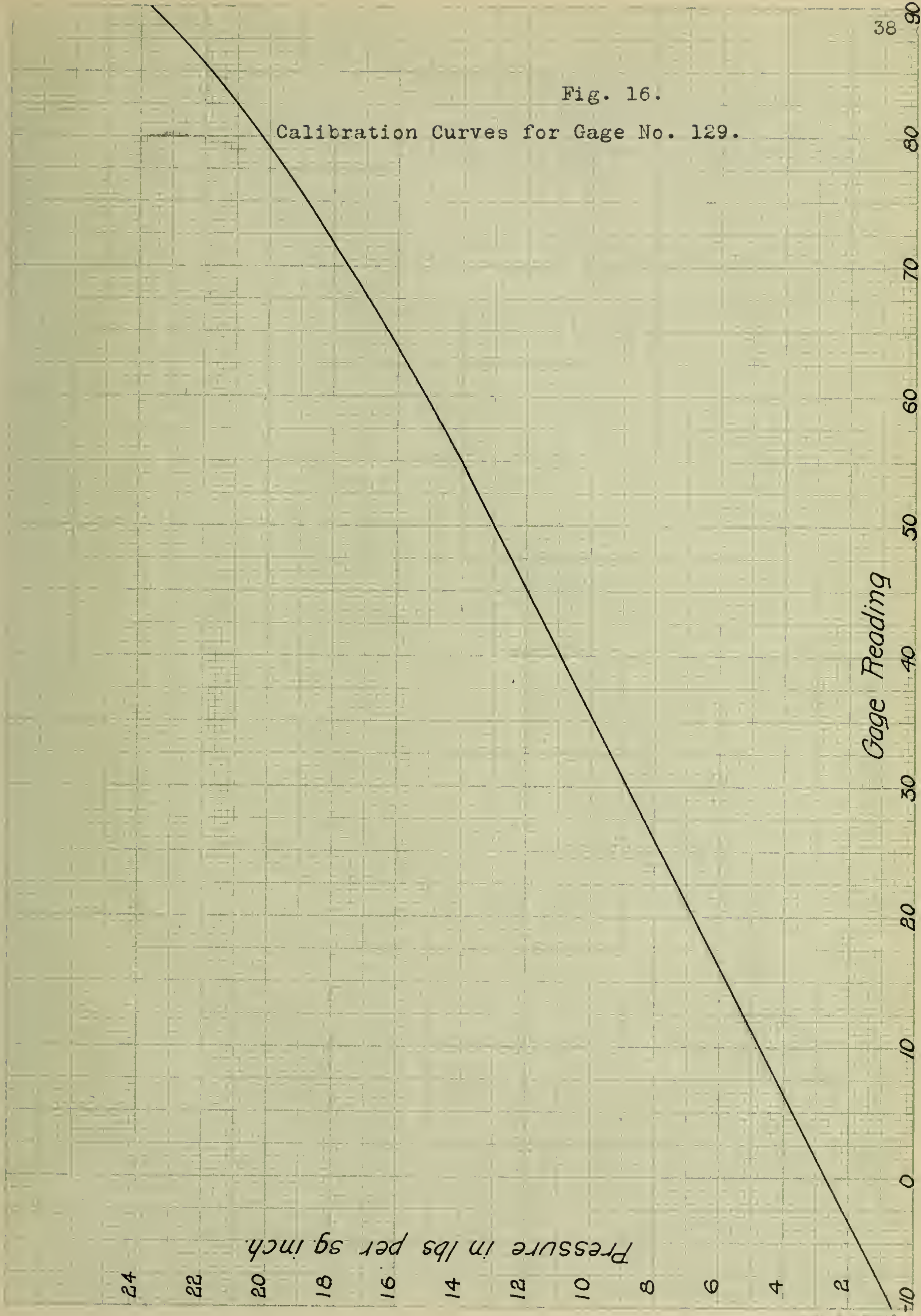
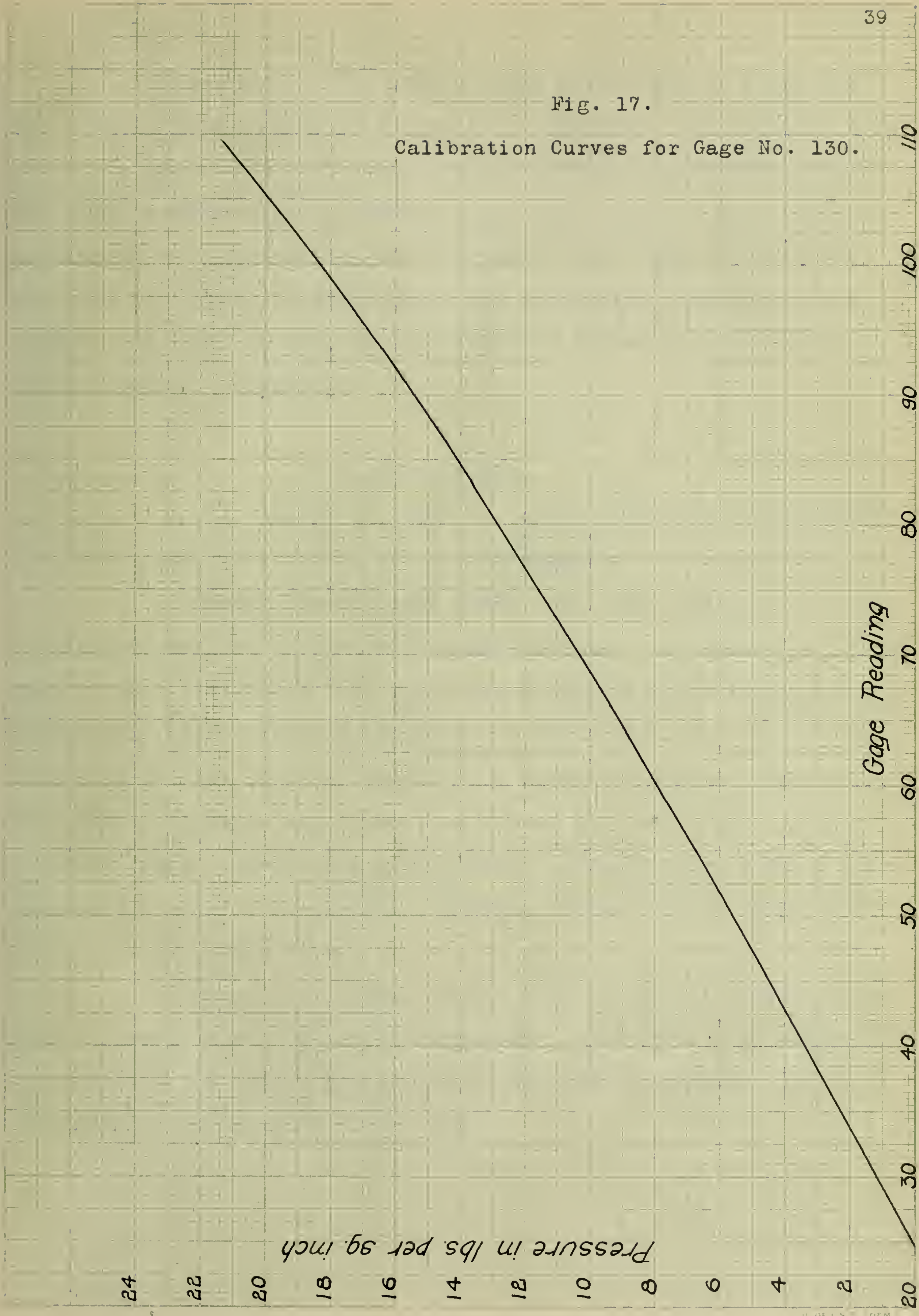


Fig. 17.

Calibration Curves for Gage No. 130.



The purpose of the intermittent method was to determine the effect of the impact of the falling concrete. The concrete was poured in layers one foot deep, and an intermission of from fifteen to thirty seconds allowed between successive layers. The highest reading on each gage during the pouring of each layer of concrete and also the lowest reading during the succeeding interval was recorded. One test on each size of the form was made by the intermittent method of pouring.

V. DATA OF TESTS.

14. Table 18, page 41, gives information concerning time of mixing and pouring, and also concerning the consistency.

Tables 19-25, pages 42-49, show the readings for heads of concrete and the corresponding gage readings. It should be noted that in each test dry broken stone was placed in the bottom of the bottom-dump bucket used in hoisting the concrete to the top of the column forms, and upon the top of this stone was spread a coat of dry plaster of paris which was then sprinkled. As a rule, a layer of stone about 3 inches thick was placed in the bottom of the 9-inch cylindrical neck of the bucket, although in the earlier tests more was used than in the later.

Fig. 18-24, pages 50-57, show the relation between head of concrete and the lateral pressure. The latter was deduced by combining the gage readings made during the experiments and results of the calibration of the gages.

Table 18

Data Concerning Mixing and Pouring

No. of Test	Time of Mixing min.	Time between end of mixing and beginning of pouring. min.	Time of Pouring min.	Consistency	Method of Pouring	Remarks
12-inch Form						
1	36½	29½	3½	Med.	Contin.	
2	28	47¼	1¾	Med.	Contin.	Leaked, and water added in skip.
3	†	†	4	Med.	Contin.	Leaked, and water added in skip.
4	32	29¾	7½	Med.	Inter.	
20-inch Form						
5	62	51	14	V. Wet	Contin.	Leaked, and water added in skip.
6	†	†	10	Med.	Contin.	Not uniform in skip.
7	90	290	10	Wet	Inter.	

† Concrete used in preceding test was wetted, remixed, and used in this test.

Table 19.

Pressure Test No. 1 - 12-inch Square Column.

Reading No.	Time Interval Sec.	Depth of Concrete Ft.	Gage Readings No. 127	No. 128	No. 129	No. 130
1	15	0	81	87	-12	24
2	15	0.45	81	87	-12	24
3	15	1.1	81	87	-12	25.5
4	15	2.0	81	87	-12	29
5	15	3.2	81	87	-12	35
6	15	4.5	81	91	-12	40
7	15	6.0	84	97.5	-12	44
8	15	7.1	86	98	-12	44
9	15	8.5	87	98	- 9	45
10	15	9.2	89	100.5	- 5.5	45
11	15	9.7	89	100.5	- 4	45
12	15	10.3	89	100.5	- 4	45
13	15	10.9	89	100.5	- 4.5	45
14	15	11.5	88.5	100.5	- 3.5	44
15	15	12.0	88	100.5	- 3.5	44
16	15	"	88	100.5	- 3.5	43
17	15	"	88	100.5	- 3.5	43
18	15	"	87	100.5	- 3.5	43
19	15	"	87	100.5	- 3.5	43
20	15	"	87	100.5	- 3.5	43
21	15	"	87	100.5	- 3.5	43
22	15	"	87	100.5	- 3.5	43
23	15	"	86.5	99.5	- 3.5	43
24	15	"	86.5	99.5	- 3.5	42.5
After being tamped		12.0	92	115	- 4	49

Height of center of gage from base, 5.6 ft. 1.8 ft. 7.6 ft. 0.5 ft.

Temperature of room, 71.5 degrees F.

Temperature of concrete, 69.5 degrees F.

Weight of concrete, 139.5 lbs. per cu. ft.

Consistency: Water equal to 10% of weight of dry materials.

December 5, 1914.

Table 20.

Pressure Test No. 2 - 12-inch Square Column.

Reading No.	Time Interval Sec.	Depth Concrete Ft.	Gage Readings No. 127	No. 128	No. 129	No. 130
1	15	0	81	87	-12	24
2	15	1	81	87	-12	26
3	15	3.5	81	87	-12	40
4	15	8.0	87	103	- 7	61
5	15	10.0	93	109	8	68
6	15	10.8	93	109	9	69
7	15	11.5	92.5	109	11	68.5
8	15	12.0	92	109	11.2	66.5
9	15		91.5	109	11.2	65
10	15		91	109	11.2	64.5
11	15		91	109	9.2	64
12	15		90.5	107	8	63.5
13	15		90.5	106.5	6.2	62.5
14	15		90	106.5	6.2	62
15	15		90	106.5	5	62
16	15		89.5	106.5	4.5	61.5
17	15		89.5	105.5	1	61
18	15		89.5	105.5	1	60.7
19	15		89.5	105.5	2	60.3
20	15		89	105.5	2	60
21	15		89	105.5	2	60
22	15		89	105.5	2	60
23	15		89	105.5	2	59.5
24	15		89	105.5	2	59
25	15		89	105.5	2	59

Height of center gage from base, 5.6 ft. 1.8 ft. 7.6 ft. 0.5 ft.

Temperature of room, 65 degrees F.

Temperature of concrete, 65 degrees F.

Weight of concrete, 138.5 lbs. per cu. ft.

Consistency, Water equal to 10% of weight of dry material.

December 10, 1914.

Table 21.

Pressure Test No. 3 - 12-inch Square Column

Reading No.	Time Interval Sec.	Depth Concrete Ft.	Gage Readings			
			No. 127	No. 128	No. 129	No. 130
1	15	0	82	87	-12	24
2	15	1.1	82	87	-12	25.5
3	15	1.9	82	87	-12	27
4	15	2.5	82	87	-12	27.5
5	15	3.4	82	90	-12	27.5
6	15	5	82	93	-12	27.5
7	15	5.9	83.5	96	-12	27.5
8	15	6.7	83.5	96	-12	27.5
9	15	7.3	85.5	97.5	-12	27.5
10	15	8	86.5	99	-10	27.5
11	15	8.5	85.5	99	- 7	27.5
12	15	9.2	85.5	99	- 5	27.5
13	15	9.7	85.5	99	- 5	27.5
14	15	10	85	99	- 5	27.5
15	15	10.4	85	99	- 5	27.5
16	15	10.9	85	99	- 5	27.5
17	15	12	85	99	- 5	27.5
18	15		85	99	- 5	27.5
19	15		85	99	- 5	27.5
20	15		85	99	- 5	27.5
21	15		85	99	- 5	27.5
22	15		85	99	- 5	27.5
23	15		85	99	- 5	27.5
24	15		85	99	- 5	27.5
25	15		85	99	- 5	27.5
26	15		85	99	- 5	27.5
27	15		85	99	- 4	27.5
28	15		85	99	- 3	27.5
29	15		85	99	- 2	27.5
30	15		85	99	- 2	27.5
31	15		85	99	- 1	27.5
32	15		85	99	0	27.5
33	15		85	99	0	27.5
34	15		85	99	1	27.5

Height of center of gage from base 5.6 ft. 1.8 ft. 7.6 ft. 0.5 ft.

Same material as in test 2.

December 10, 1914.

Table 22.

PRESSURE TEST NO. 4 - 12-INCH SQUARE COLUMN.

Reading No.	Time Interval Sec.	Depth Concrete Ft.	Gage Readings. No. 127	No. 130
1		0	81.5	24
2	60	1.5	81.5	26.5
3	25	1.5	81.5	25.9
4	15	2.5	81.5	26.5
5	25	2.5	81.5	26.2
6	10	3.5	81.5	26.6
7	20	3.5	81.5	26.2
8	20	4.5	81.5	26.4
9	30	4.5	81.5	26.4
10	7	5.5	83	26.4
11	29	5.5	82.5	26.4
12	12	6.5	85	26.4
13	27	6.5	84.5	26.4
14	3	7.5	84.5	26.4
15	27	7.5	85	26.4
16	20	8.5	86.5	26.4
17	27	8.5	86	26.4
18	13	9.5	86.5	26.4
19	31	9.5	86	26.4
20	9	10.5	85.5	26.4
21	30	10.5	85.5	26.4
22	10	11.5	85	26.4
23			85	26.4
24			85	26.4
25			84.5	26.2
26			84.5	26.2
27			84.5	26.2

Height of center gage from base 5.6 ft. 0.5 ft.

Temperature of room, 65.5 degrees F.

Temperature of concrete, 65.5 degrees F.

Weight of concrete, 139.06 lbs. per cu. ft.

Consistency, Water equal to 10% of weight of dry materials.

December 12, 1914.

Table 23.

PRESSURE TEST NO. 5 - 20-INCH SQUARE COLUMN.

Reading No.	Time Interval Sec.	Depth Concrete Ft.	Gage Readings No. 127	No. 128	No. 129	No. 130
1	15	0	81	87	-12	24
2	15	0.15	81	87	-12	24
3	15	0.3	81	87	-12	24
4	15	0.5	81	87	-12	24
5	15	0.7	81	87	-12	25.5
6	15	0.9	81	87	-12	26
7	15	1.05	81	87	-12	27
8	15	1.2	81	87	-12	27
9	15	1.35	81	87	-12	27.
10	15	1.51	81	87	-12	27.5
11	15	1.7	81	87	-12	28.
12	15	1.83	81	87	-12	28.5
13	15	2	81	87	-12	29
14	15	2.1	81	87	-12	30
15	15	2.21	81	87	-12	30.5
16	15	2.3	81	87.5	-12	32
17	15	2.43	81	88	-12	33
18	15	2.6	81	88.5	-12	33
19	15	2.8	81	90.5	-12	34.5
20	15	3	81	91	-12	35
21	15	3.15	81	91.5	-12	35.5
22	15	3.35	81	92	-12	36.5
23	15	3.5	81	92.5	-12	38.5
24	15	3.7	81	92.5	-12	39
25	15	3.83	81	93	-12	40
26	15	4	81	93.5	-12	41
27	15	4.13	81	94	-12	41.5
28	15	4.28	81	94.5	-12	41.5
29	15	4.4	81	95.5	-12	42.5
30	15	4.55	81	96	-12	42.5
31	15	4.7	81	96.5	-12	43
32	15	4.8	81	96.5	-12	43
33	15	4.9	81	97	- 9.5	45.5
34	15	5	81	97.5	- 7	45.5
35	15	5.1	81	98.5	- 5	45
36	15	5.2	81	99	- 4	44.5
37	15	5.36	81	100	- 3	44.5
38	15	5.5	81	100	- 2	44.5
39	15	5.7	81.5	100.5	- 2	44.5
40	15	5.95	81.5	100.5	- 1.5	44.5
41	15	6.2	83	100.5	0.5	44.5
42	15	6.3	84.5	100.5	3	44.5
43	15	6.5	85	100.5	3.5	44.5
44	15	6.8	85	100.5	3.5	44.5
45	15	7.05	85.5	100.5	3.5	44.5

Table 23. (Continued)

PRESSURE TEST NO. 5 - 20-INCH SQUARE COLUMN.

Reading No.	Time Interval Sec.	Depth Concrete Ft.	Gage Readings No. 127	No. 128	No. 129	No. 130
46	15	7.2	86.5	100.5	4.5	44.5
47	15	7.35	86.5	100.5	5.5	44.5
48	15	7.5	87.5	100.8	7.5	44.5
49	15	7.7	87.5	100.8	9	44.5
50	15	7.85	87.5	100.8	9.6	44.5
51	15	8.05	87.5	100.8	10.2	44.5
52	15	8.25	87	100.8	12.2	44.5
53	15	8.5	87	100.8	12.4	44.5
54	15	8.65	87	100.8	13	44.5
55	15	8.9	87	100.8	13	44.5
56	15	9.1	87	100.8	13	44.5
57	15	9.35	87	100.8	13	44.5
58	15	10.3	87	100.8	13	44.5
59	15	12	87	100.8	13	44.5
60	15		87	100.8	13	44.5
61	15		87	100.8	13	44.5
62	15		87	100.8	13	44.5
63	15		87	100.8	13	44.5
64	15		87	100.8	13	44.5
65	15		87	100.8	13	44.5
66	15		86.5	100.8	13	44.5
67	15		86.5	100.8	13	44.5

Height of center gage from base, 5.6 ft. 1.8 ft. 3.5 ft. 0.5 ft.

Temperature of room, 63.5 degrees F.

Temperature of concrete, 62 degrees, F.

Weight of concrete, 141.71 lbs. per cu. ft.

Consistency, Water equal to 12% of weight of dry material.

December 22, 1914.

[illegible]

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[illegible]

[illegible]

[illegible]

Table 24.

PRESSURE TEST NO. 6. - 20-INCH SQUARE COLUMN.

Reading No.	Time Interval Sec.	Depth of Concrete Ft.	Gage Readings No. 127	No. 128	No. 129	No. 130
1	15	0	81	87	-12	24
2	15	0.5	81	87	-12	24
3	15	0.7	81	87	-12	24.5
4	15	0.9	81	87	-12	24.5
5	15	1.1	81	87	-12	24.8
6	15	1.35	81	87	-12	24.8
7	15	1.55	81	87	-12	25.5
8	15	1.82	81	87	-12	26.3
9	15	2.32	81	87.5	-12	28.5
10	15	2.85	81	88	-12	28.8
11	15	3.32	81	89	-12	29
12	15	3.65	81	89.5	-12	29.5
13	15	3.87	81	91.5	- 8.2	29.5
14	15	4.21	81	92	- 7.2	29.5
15	15	5	81	92.5	- 4.7	32.5
16	15	5.72	83.5	97	4.3	31.5
17	15	6.5	84	98.5	6.6	30.5
18	15	7.2	84.5	99	8.5	30.7
19	15	7.72	86	99	8.7	30.7
20	15	8.2	87	102	12.7	32
21	15	8.65	88	103	14.6	31.8
22	15	9	89	104	16.8	31.5
23	15	9.3	89	105	19.8	31.3
24	15	9.6	89.5	105.5	20.3	31
25	15	9.9	89.5	105.5	20.6	30.7
26	15	10.21	90	105.5	20.8	30.5
27	15	10.48	90	105.5	20.8	30.5
28	15	10.7	90	105.5	20.8	30.6
29	15	10.88	90	105.5	20.3	30.7
30	15	11.07	90	105.5	20.3	30.7
31	15	11.22	90	105.5	20	30.6
32	15	11.35	90	105.5	20	30.5
33	15	11.4	90	105.5	20	30.6
34	15	11.51	90	105.5	20	30.7
35	15	11.59	90	105.5	19.8	30.7
36	15	11.68	90	105.5	19.6	30.5
37	15	11.77	90	105.5	19.6	30.5
38	15	11.84	90	105.5	19.6	30.6
39	15	11.9	90	105.5	19.5	30.7
40	15	11.92	90	105.5	19	30.7

Height of center of gage from base, 5.6 ft. 1.8 ft. 3.5 ft. 0.5 ft.

Same material as in Test 5.

December 22, 1914.

Table 25.

PRESSURE TEST NO. 7. - 20-INCH SQUARE COLUMN.

Reading No.	Time Interval Sec.	Depth of Concrete Ft.	Gage Readings No. 127	No. 128	No. 129	No. 130
1	15		81.7	+87.5	-12.5	24
2	15		81.7	87.5	-12.5	31.5
3	15		81.7	87.5	-12.5	31.5
4	15		81.7	87.5	-12.5	31.5
5	15	1.5	81.7	87.5	-12.5	31.5
6	15	1.5	81.7	87.5	-12.5	31.5
7	15	2.5	81.7	89.5	-12.5	37.5
8	15	2.5	81.7	89.5	-12.5	37.5
9	10	3.5	81.7	93.5	-12.5	42.0
10	15	3.5	81.7	93.5	-12.5	44
11	25	4.5	81.7	96.5	- 2.5	48
12	15	4.5	81.7	96.5	- 2.5	49.5
13	17	5.5	81.7	100	2.5	52.5
14	15	5.5	81.7	100	2	52.5
15	18	6.5	85.2	101	9	55.5
16	15	6.5	85.2	101	8.7	55.5
17	31	7.5	86.7	102	13	56.5
18	15	7.5	86.7	102	12.4	56.5
19	31	8.5	89.2	102	15.5	56
20	15	8.5	89.2	102	14.7	56.5
Tamped		12	91.2	102	15	54.5
Height of center gage from base			5.6 ft.	1.8 ft.	3.5 ft.	0.5 ft.

Temperature of room, 60 degrees F.

Temperature of concrete, 62 degrees F.

Weight of concrete, 140.15 lbs. per cu. ft.

Consistency, Water equal to 9% of weight of dry material.

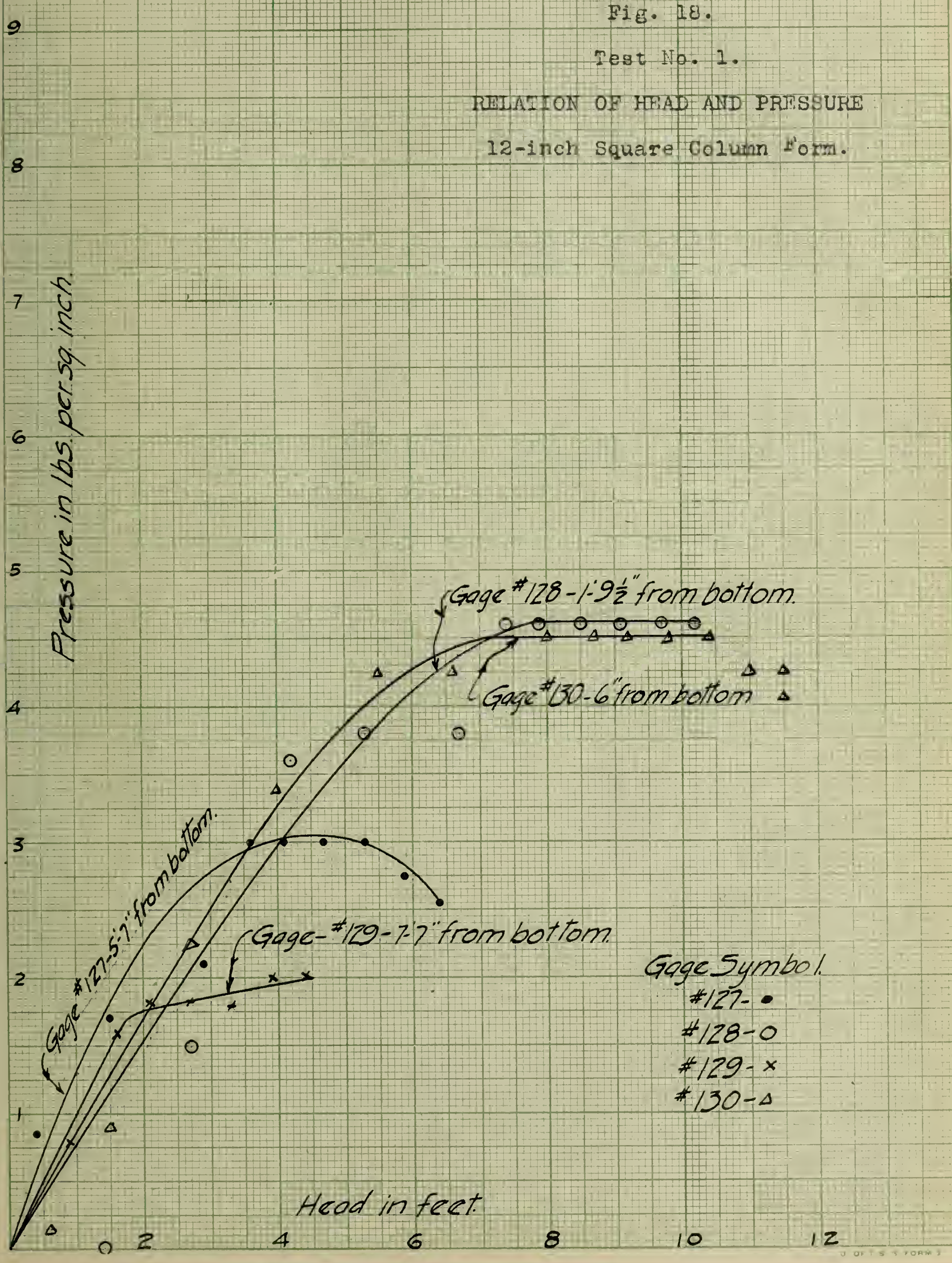
January 21, 1915.

Fig. 18.

Test No. 1.

RELATION OF HEAD AND PRESSURE

12-inch Square Column Form.



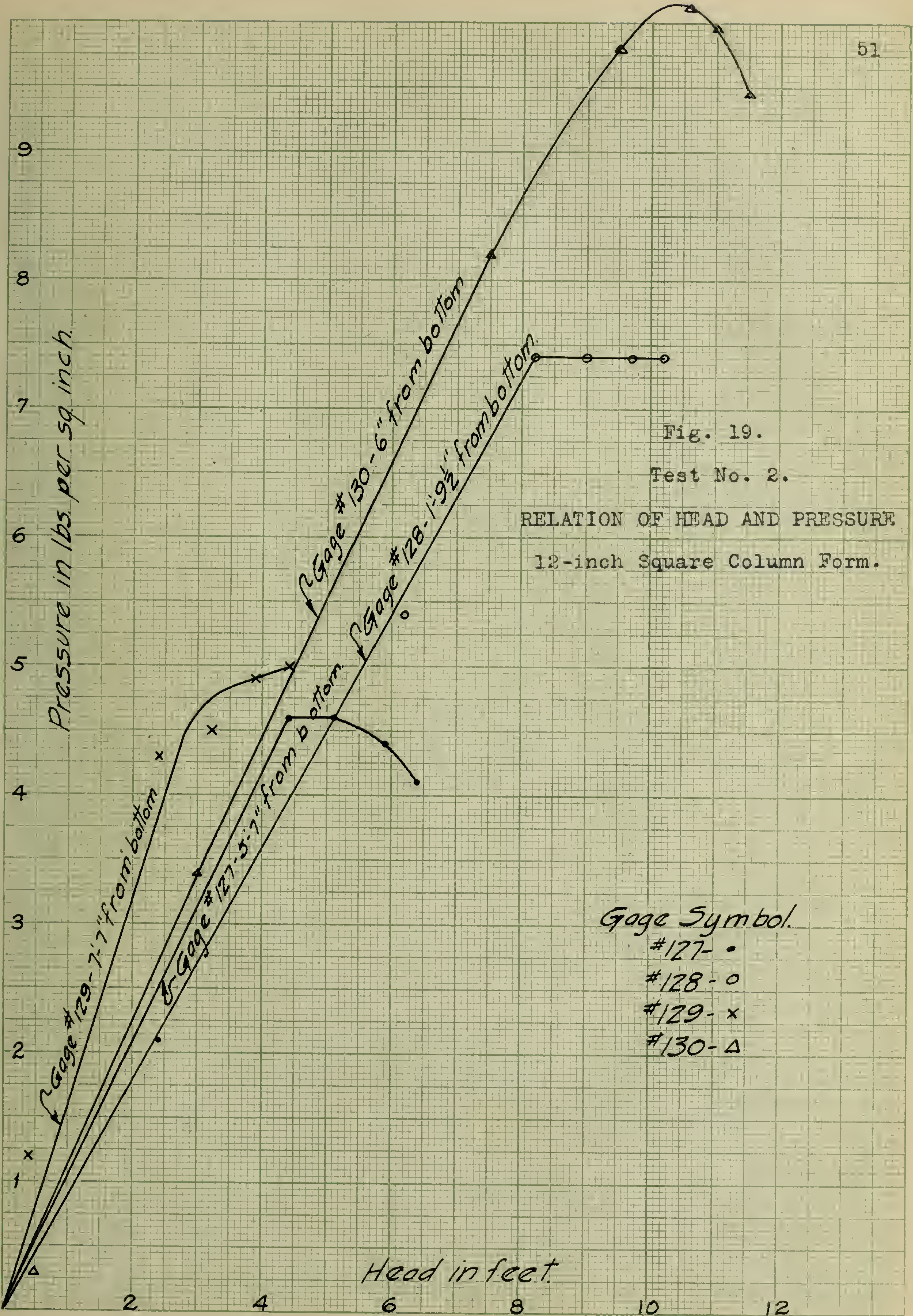


Fig. 19.

Test No. 2.

RELATION OF HEAD AND PRESSURE

12-inch Square Column Form.

Fig. 20.

Test No. 3.

RELATION OF HEAD AND PRESSURE

12-inch Square Column Form.

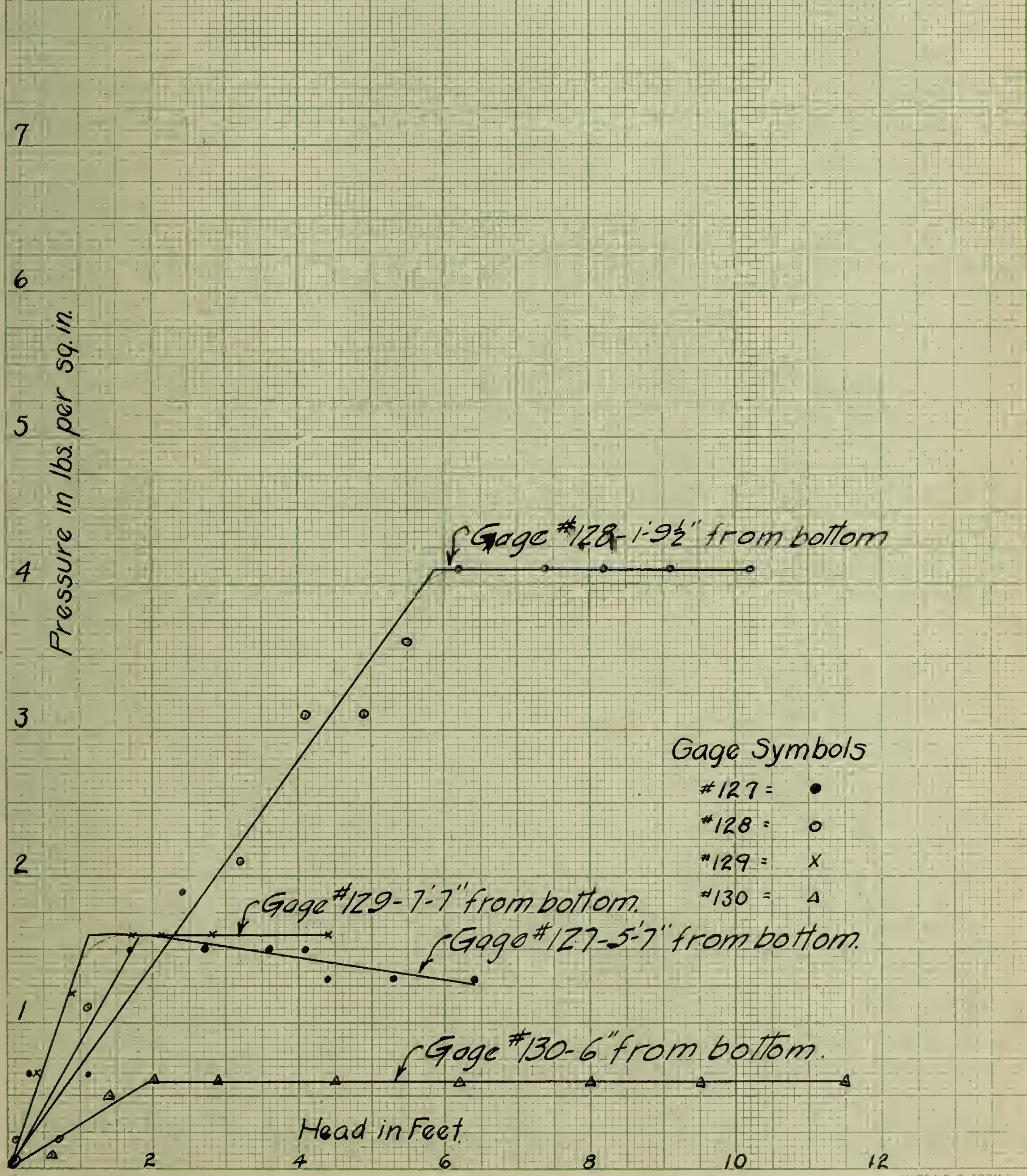


Fig. 21.

Test No. 4.

RELATION OF HEAD AND PRESSURE

12-inch Square Column Form.

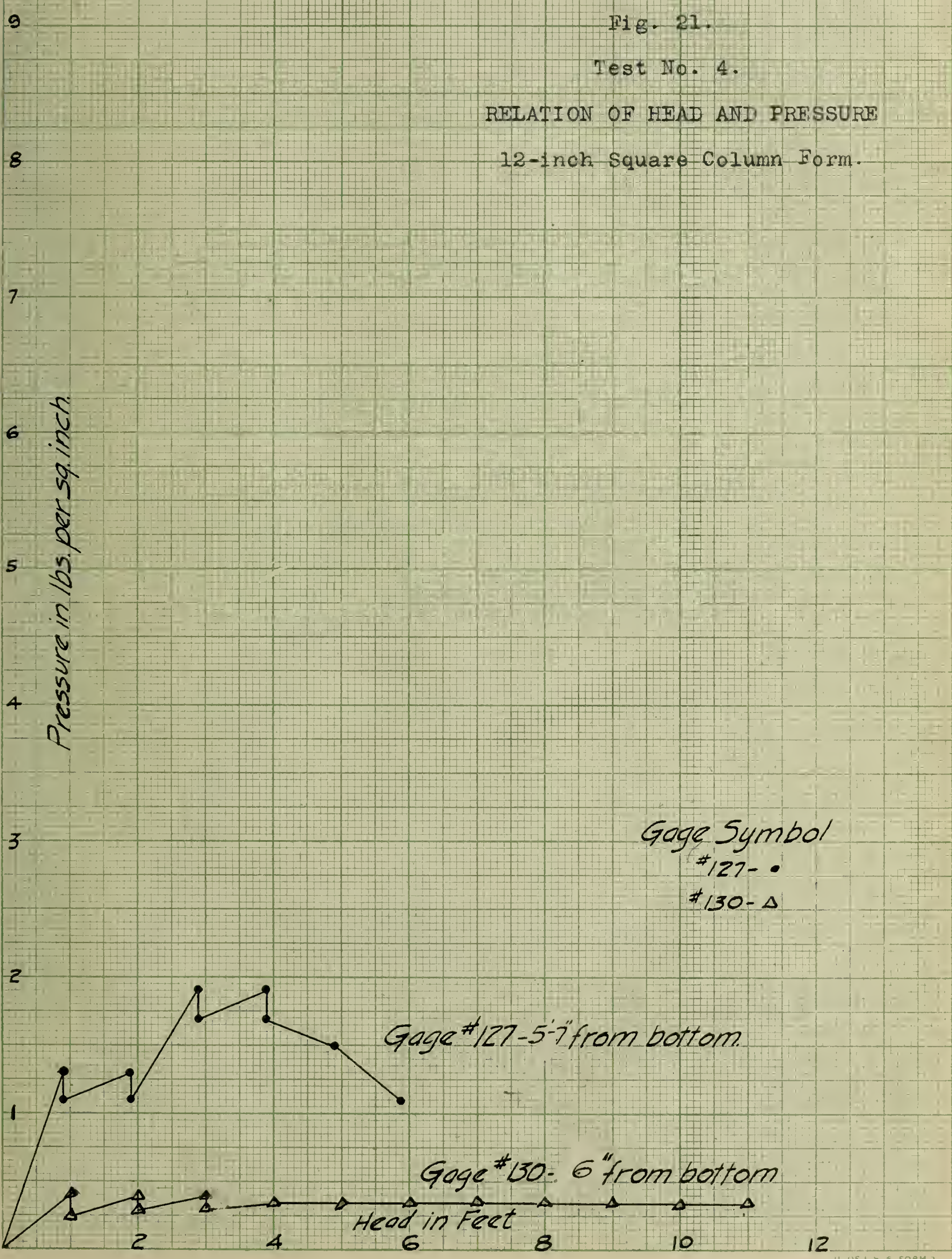


Fig. 22.

Test No. 5.

RELATION OF HEAD AND PRESSURE

20-inch Square Column Form.

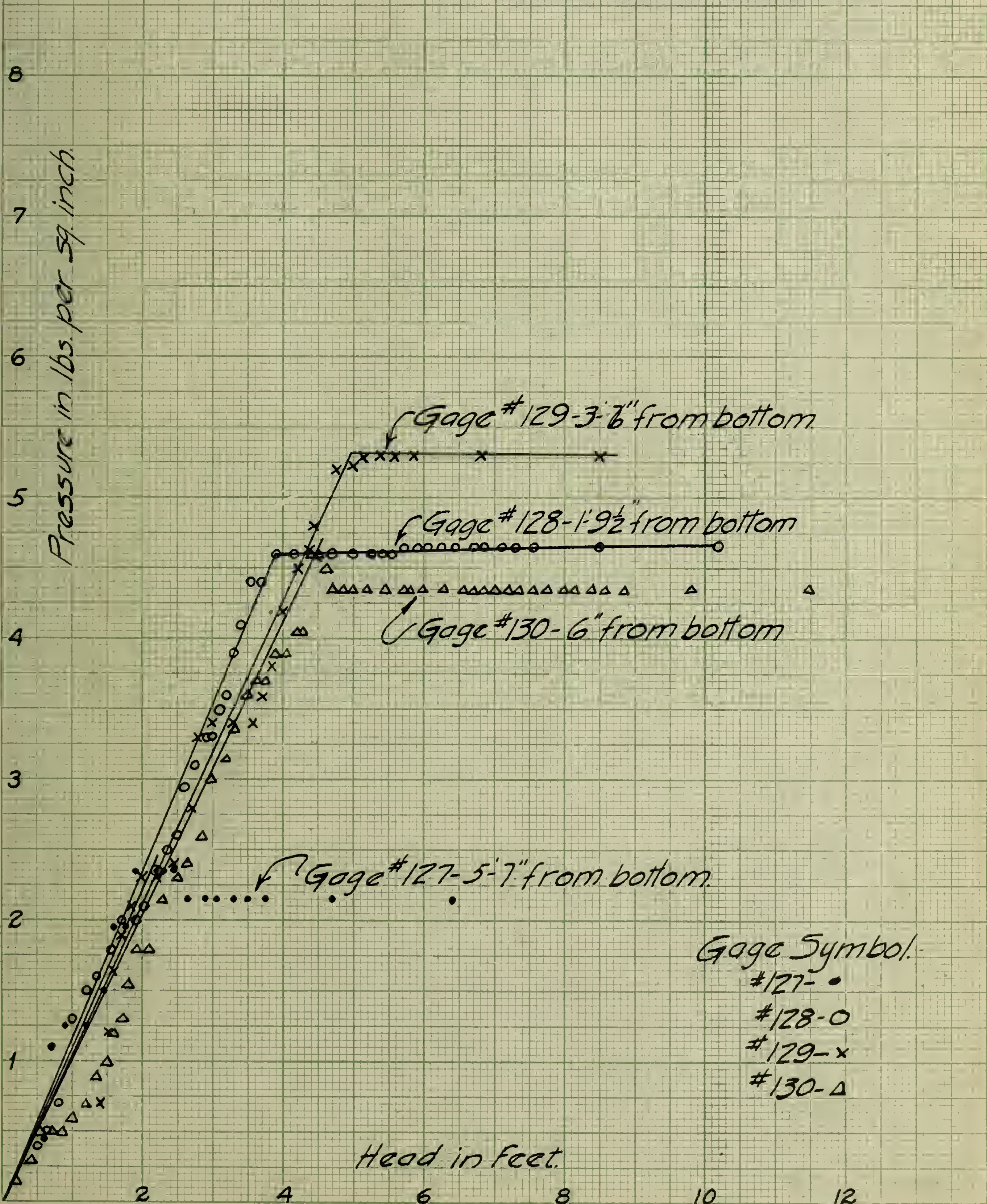


Fig. 23.

Test No. 6.

RELATION OF HEAD AND PRESSURE

20-inch Square Column Form.

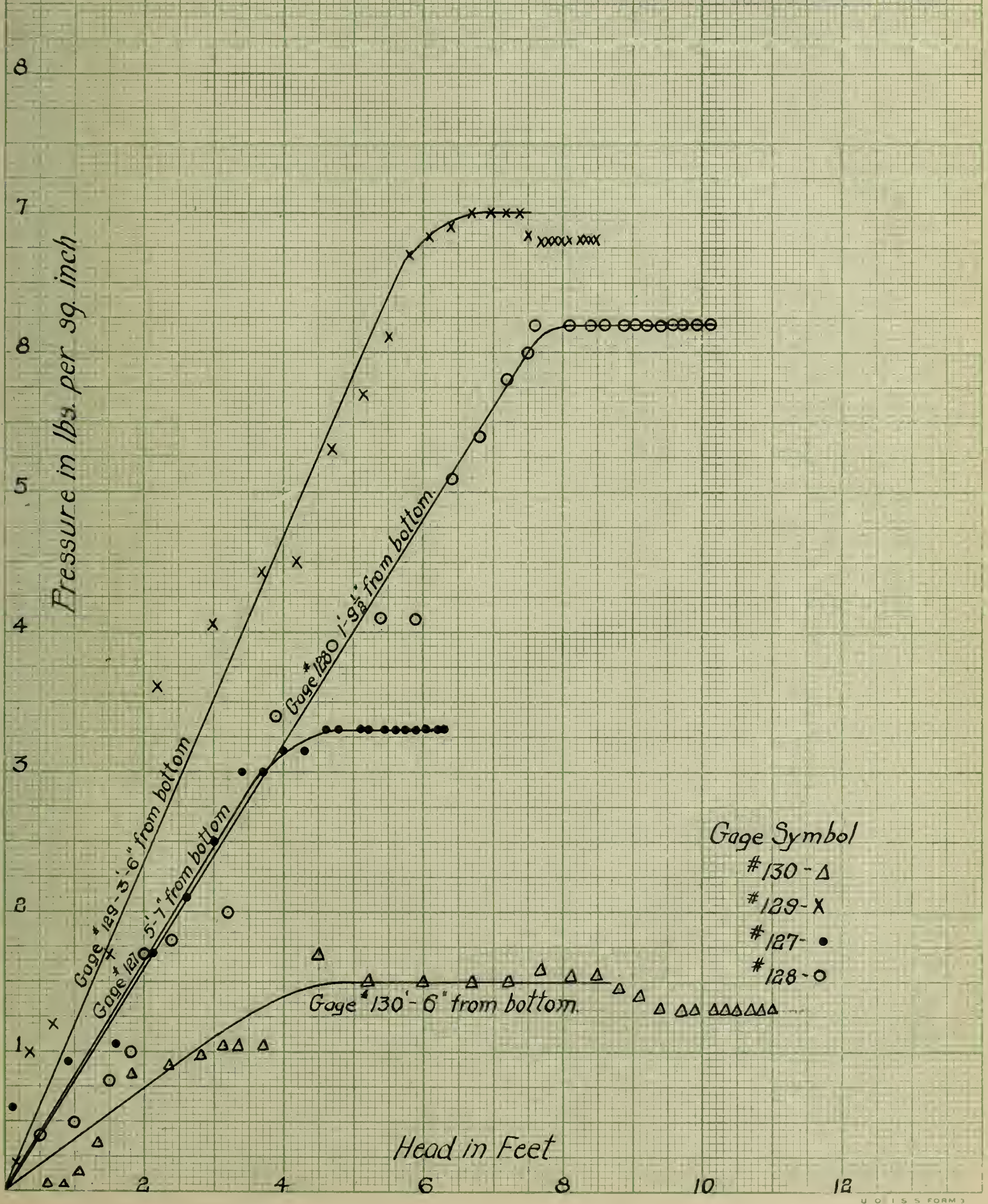
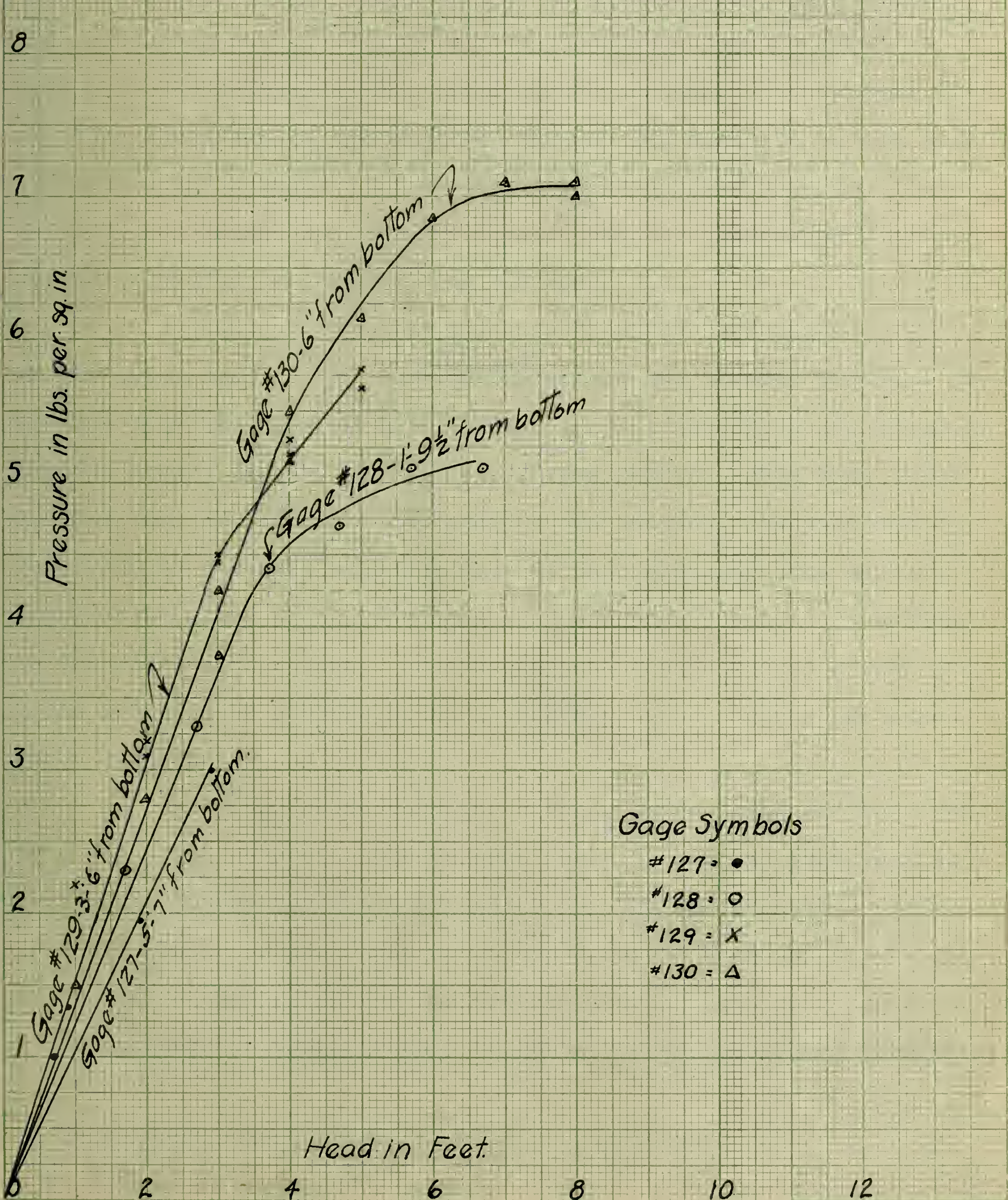


Fig. 24,

Test No. 7.

RELATION OF HEAD AND PRESSURE

20-inch Square Column Form.



VI. DISCUSSION OF TESTS.

15. PLOTTED DATA. The points representing the lateral pressures by each of the four gages for each of the seven tests are plotted in Fig. 18-24, pages 50-56. To eliminate as far as possible the accidental errors of observation, a smooth line was drawn to represent the average of the results for each gage. On account of the wide variation of the observed values, the position of the line representing the mean value could not be determined with any considerable accuracy; but it is believed that the drawing of these lines is helpful in interpreting the data.

A study of the curves for each of the four gages in each of the seven tests shows that in most cases the lateral pressure increases with the head up to a certain point, after which the pressure remains nearly constant until the pouring ceases. This fact seems to show that during the first part of the pouring, the concrete is supported by pressure upon the base of the form, and that later a considerable part of the concrete is supported by arch-like action on the sides of the form. In this respect the action of green concrete seems to be similar to that of grain, seeds, clean dry sand, etc., in a bin. *

While the above conclusion seems to be borne out in a general way, the curves for the several gages in any one test vary so much among themselves and the results for the several tests differ from each other so much that it is not possible from the curves of Fig. 18-24 to determine the law of the lateral pressure with any greater degree of accuracy than is stated in the preceding paragraph.

*See Baker's Masonry Construction, p. 500-02.

In an attempt to determine more accurately the law of the lateral pressure, all of the data of all of the tests were plotted on a single sheet -- see Fig. 25, page 59. Then by eye a curve was drawn to represent the average of all of the experiments. This line is labeled "Line of Average Pressure". This line seems to show that the lateral pressure decreases as the head increases, which is in accordance with the observed results with grain in bins. This line is not well enough determined and the range of experiments is too small to warrant any conclusion as to the head at which the lateral pressure becomes constant.

Since a general study of Fig. 18-24 and of Fig. 25 does not warrant any definite conclusion, a further attempt to deduce a general conclusion was made by computing the lateral pressure from the "Line of Average Pressure" shown in Fig. 18-24, for each foot of head for each gage in each test. Of course, such a method of investigation can not lead to results of any considerable accuracy, since the results are based upon a line drawn by eye to represent the average of a number of erratic values; but it was hoped that the results would give an arithmetical expression of the reliability of the line in Fig. 25, page 59, representing the average lateral pressure. However, the result of this investigation was very disappointing, since the values were too erratic to establish any trustworthy conclusion.

Since Fig. 25, seems to show that green concrete at the lower heads acts somewhat as a liquid, it was thought that a determination of the lateral pressure for, say, a head of one foot for each gage in each of the tests would give some evidence as to the reliability of the slope of the line for equivalent liquid pressure in Fig. 25.

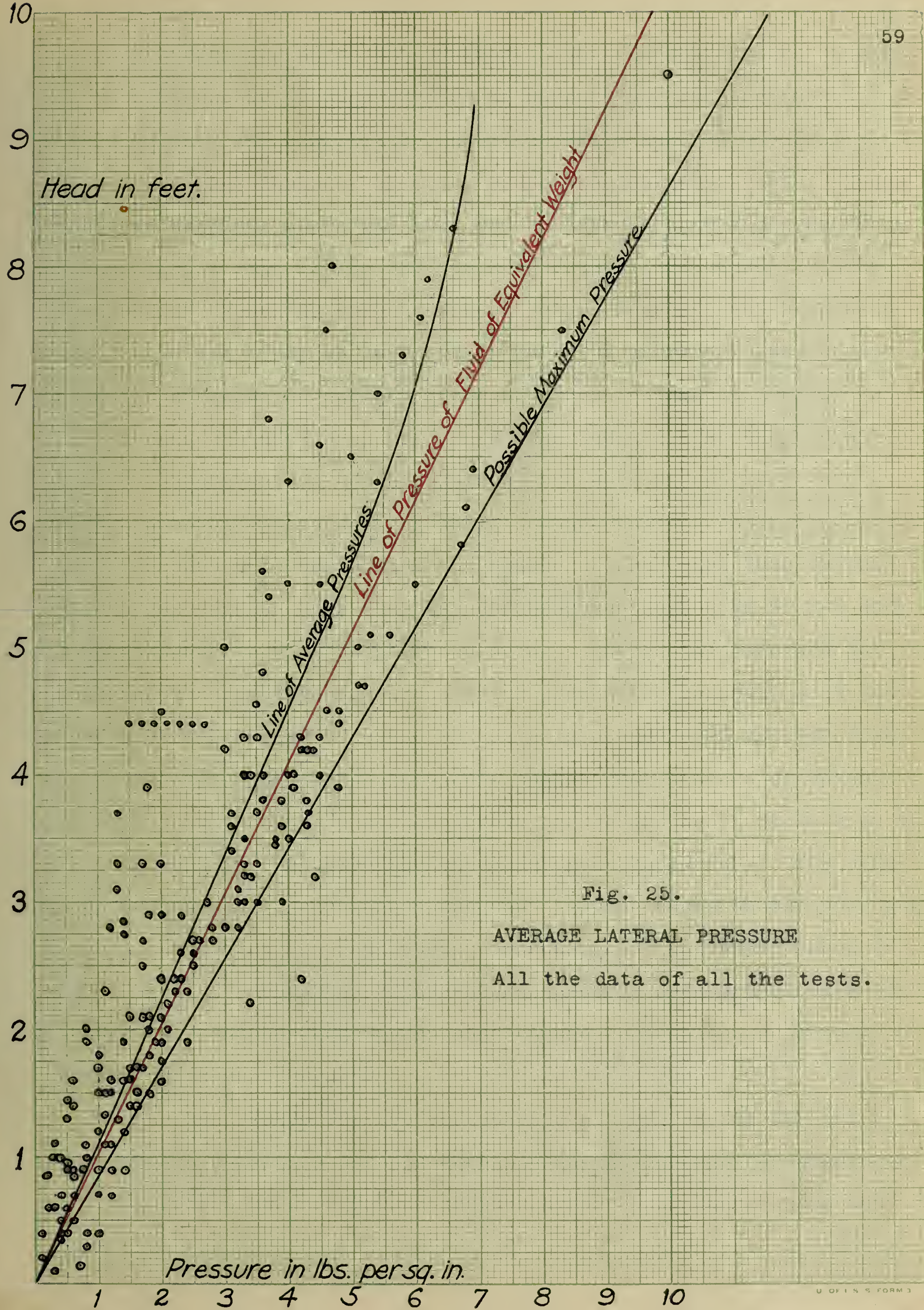


Fig. 25.

AVERAGE LATERAL PRESSURE

All the data of all the tests.

Table 26, page 61, shows the results of this investigation. Apparently the results are too erratic to warrant any conclusions of positive value. For example, the pressure for a head of one foot varies from 116 to 187 lbs., or in other words the lateral pressure of green concrete weighing about 141 lbs. per cu. ft. acts as a liquid whose weight varies from 116 to 187 lbs. per cu. ft. Of course, a mean obtained by averaging such divergent values would be quite unreliable. A little study of the data in Table 26 shows that no conclusion can be drawn concerning the difference in lateral pressure in a 12-inch and 20-inch form, for continuous pouring, for the average of all the experiments with the 12-inch form gave a pressure for a 1-foot head of 144 pounds, while all experiments on the 20-inch form gave 136 pounds. Considering the nature of the data, this difference is too small to warrant any definite conclusion as to the relative pressure in the two sizes of forms. Again, the data are too variable to establish any trustworthy conclusion regardless of the method of pouring, as to the difference in pressure in the two sizes of forms, for with the 12-inch form the average lateral pressure from all the four tests is 137 pounds per square foot, while with the 20-inch form the pressure is 153 pounds per square foot. The only conclusions that can be drawn are that (1) the tests do not give any trustworthy value for the lateral pressure, (2) the experiments do not show any trustworthy difference in lateral pressure between the 12-inch and the 20-inch forms, nor between continuous and intermittent methods of pouring.

One reason for the variability of the results for the pressure as stated in the preceding paragraph is that the pressures given in Table 26 were not determined directly by observation but

Table 26.

LATERAL PRESSURE FOR A HEAD OF ONE FOOT.

12-inch Form			20-inch Form		
Test No.	Gage No.	Lateral Pressure lbs. per sq. ft.	Test No.	Gage No.	Lateral Pressure lbs. per sq. ft.
CONTINUOUS POURING			CONTINUOUS POURING		
1	127	187	5	127	158
	128	115		128	169
	129	144		129	151
	130	126		130	144
	Average	143		Average	156
2	127	151	6 +	127	123
	128	130		128	115
	129	230		129	173
	130	169		130	54
	Average	169		Average	116
3 *	127	122			
	128	101			
	129	209			
	130	43			
	Average	119			
INTERMITTENT POURING.			INTERMITTENT POURING		
4	127	173	7	127	151
	128	---		128	180
	129	---		129	223
	130	48		130	194
	Average	110		Average	187

*The concrete used in this test was that of No. 2 re-tempered.

+The " " " " " " " " No. 5 " .

were scaled from a line plotted to represent the average pressures. If direct observations had been made to determine the pressure for one foot of head possibly more concordant results would have been obtained.

The results may be studied by considering the direction of the curvature of the line of pressure and its significance. If the concrete acts strictly as a liquid, the pressure will be represented by a straight line passing through the origin. If the line representing the pressures is convex toward the pressure axis, then the concrete does not act strictly as a liquid, and the line of pressures tends to become parallel to the axis of head, i.e., the lateral pressure tends to become constant at some head, in which case the green concrete acts like grain in a bin.

In Fig. 18-24 practically all of the lines representing the average pressure for the lower heads are straight, and therefore we may conclude that in the main the tests show that the green concrete acted as a liquid. The four lines as drawn in Fig. 18, page 50, are convex toward the pressure axis; but an inspection of the individual results shows that the lower portion of the line could with equal propriety have been drawn straight rather than curved. Therefore, we may conclude that all of the gage readings in all of the tests show that for the lower heads the concrete acted as a liquid mass.

An examination of all of the lines representing the average gage readings shows that for the higher heads the line representing the pressure tends to become parallel to the axis of head, which shows that for the higher heads at least part of the weight of

the concrete is supported by arch-action on the sides of the forms. In other words, all of the gage readings seem to show that the concrete in these tests acted very much as grain in bins.

16. STUDY OF ERRATIC RESULTS. Since it seemed impossible to deduce any valuable conclusion from the average of the several tests, a study was made of the readings of the individual gages.

One of the most striking features shown by the gage readings is that in test No. 3, Fig. 20, page 52, gage No. 130 gives a smaller pressure than any of the other three, although it has the greater head. A similar result for gage No. 130 occurs in test No. 4, Fig. 21, page 53, and also for the same gage in test No. 6 -- see Fig. 23, page 55. Apparently the explanation is: Dry stone was put into the bottom-dump skip to prevent the loss of water while hoisting the skip into position for pouring, and it is probable that the dry material dammed up in front of gage No. 130 (the lowest one) and prevented the liquid portion of the concrete from acting upon the diaphragm of the gage.

In test No. 1, gage No. 128 gave a larger reading than gage No. 130, although the latter had the greater head. Apparently the only explanation of this anomalous result is that the dry stone that was put into the skip lodged in front of gage No. 128 and prevented the liquid concrete from acting on the diaphragm. This explanation is made the more probable because of the fact that in this test, considerable trouble was experienced in getting the concrete to flow from the skip.

17. CAUSES OF ERRATIC RESULTS. Several causes operated to produce a variation of observed values. Among these are:

1. Owing to the leakage of water from the skip during the

process of hoisting, the concrete was not uniform in consistency for the different tests, and was even different in consistency in different parts of the skip during the same test.

2. The traveling crane with which the concrete was hoisted was so difficult to operate that in several cases the concrete in the skip had time to take initial set before pouring took place.

3. A great deal of trouble was experienced in getting the concrete to flow from the skip, and consequently a uniform rate of pouring was not obtained throughout the pouring of any one test.

4. In two of the tests the concrete used was that employed in the previous test. It was retempered and remixed, but there is a possibility that initial set had taken place before the concrete was placed in the forms. It is possible that even a little initial set would materially change the pressure of the concrete mass, and thereby materially affect the observed pressure.

5. The dry stone put into the bottom of the skip to prevent leakage of water seems to have blocked some of the gages. This point has already been considered, see second and third paragraphs of Section 16, page 63.

6. In mixing the concrete an attempt was made to keep the consistency constant, and this was checked by determining the weight per cubic foot of the concrete. The weight varied from 138.5 to 141.71 pounds per cubic foot, which for such experiments seems reasonably accurate; but the bottom dump-bucket or skip used in raising the concrete to the top of the form permitted considerable water to leak out, and in nearly every case water was added

in the skip. It is not certain that the resultant consistency was that of the concrete originally, nor that the consistency was uniform in the mass.

7. There were so few tests made under exactly the same conditions (see Table 26, page 61) that there is not much opportunity to eliminate accidental errors of observation by combining a considerable number of the results. For example, only two tests (Tests 1 and 2) were made under nominally the same conditions. Test 3 was made under the same conditions as 1 and 2, except that the mortar used in No. 2 was retempered and used again in No. 3; and Tests 5 and 6 were under the same conditions, except that the mortar used in the first was retempered and used again in the second.

8. There was a chance for pieces of stone projecting over the side of the diaphragm and preventing the concrete from acting upon the gage; and on the other hand there was a possibility that a corner of a fragment of stone could project against the diaphragm and give an unduely large reading. If the concrete contained a considerable amount of fluid mass, neither of these results would be likely to occur; but a study of the individual readings of the several gages seems to show that some such cause must have operated, at least some of the readings are abnormally high and some abnormally low.

9. It is unfortunate that the work of pouring the concrete into the forms was entirely completed before any considerable study was made of the results; and consequently no attempt was made to profit by the experience with a test before making the succeeding one.

18. EFFECT OF IMPACT. Before making the experiments, the general belief was that the impact of the dropping concrete would affect the gage readings; and therefore a variation in the method of pouring was adopted which was then believed would give data from which the effect of impact could be determined. Note that Tests 1, 2, 3, 5, and 6, pages 51, 52, 53, 55, and 56, were made by continuous pouring; and that Tests 4 and 7 were made by what is designated as intermittent pouring. In the two latter tests, the concrete was poured into the forms continuously for about fifteen seconds, until a depth of one foot had been deposited: pouring ceased for fifteen seconds, and was then resumed until a succeeding foot in depth had been added. While the concrete was being deposited, the mercury column of the gage advanced somewhat intermittently but continuously until the pouring ceased, then the mercury column receded slightly; and when the pouring began again, the pressure continued to rise. For some unknown reason, in Test 4 only two gages gave reasonably satisfactory readings. These two gages gave records somewhat similar.

At the time of making the tests, it was believed that the steps in the lines shown in Fig. 2, page 53, measured the effect of impact; but it is not certain that this is the case. It is significant to notice the marked difference in character between the pressure lines in Fig. 21 and those in Fig. 24, although the method of pouring was the same in both cases. The lines in Fig. 24 for intermittent pouring have the same characteristics as those for the five tests with continuous pouring.

A consideration of the readings for gage 130, Fig. 21, page 54, seems to show that the depth of concrete above the gage

decreases the effect of impact, and that when the depth is something like four feet, the effect of impact is zero; but an examination of the record for gage 127, in the same test, seems to show that the so-called impact effect is substantially the same for a one-foot head as for a four-foot head. Therefore, the conclusion seems to be that as far as these tests show, the effect of concrete above gage has no effect upon the pressure due to impact.

If the line of pressure were convex toward the axis of head, then the pressure increases more rapidly than the head and the lateral pressure would be more than that due to a liquid having a weight equal to that of the concrete. Such a curvature of the line of pressure would indicate that there must be some force acting upon the concrete other than its weight. Apparently the only force that could produce this effect is the impact of the falling concrete. An examination of the pressure lines in the several tests shows that none of them are convex toward the axis of head; and therefore as far as can be determined by this line of investigation, the tests give no evidence that the pressure due to impact is appreciable.

Since the pressure lines for the two tests by intermittent pouring (tests 4 and 7, Fig. 21 and 24) differ so radically, and since there is no other evidence of the effect of impact, the conclusion is that the steps in Fig. 21, page 53, may not be due to impact.

It is certain that the results give no definite information as to the effect of impact, and it is not certain that the tests give any evidence of the presence of any such effect.

19. CONCLUSION. The unsatisfactory results of the tests reported in this thesis clearly show the necessity for a more careful and accurate method of conducting the work.

The construction of a reinforced concrete viaduct at Danville, Illinois, was begun during the compilation of the data of this thesis; and arrangements have been completed for making some tests on the lateral pressure of the concrete in connection with that construction. The observations will be taken by two instructors of the Department of Civil Engineering on the diaphragm pressure gages used in this thesis work. The gages will be placed near the bottom of the forms of the spandrel posts which are 23 by 30 inches in cross-section and about 18 feet high. The concrete will be deposited by the spouting system. The consistency of the concrete will be regulated at the mixer, and its flow will be controlled at the hopper on the pouring tower and also at the top of the forms. Every precaution will be taken to secure favorable conditions for the tests.